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U.S. Quarterly Demand for Meats

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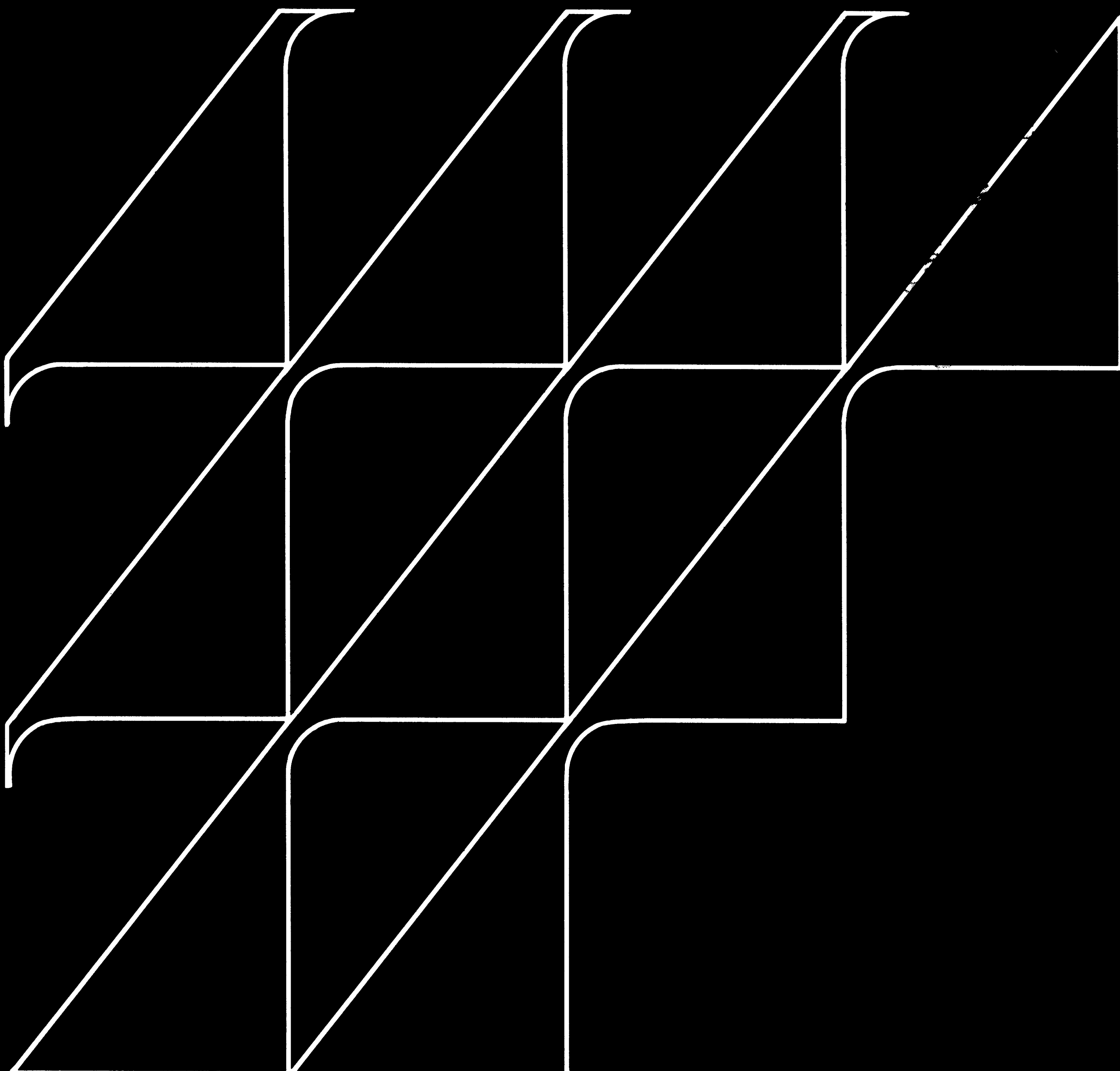

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Abstract

This study estimates a model of U.S. quarterly demand for meats with application to nutrition and other empirical issues. The estimated demand model is useful for improving forecasts of shortrun meat prices and consumption and for program analysis.

Keywords: Consumer welfare, demand structural change, elasticities, flexibilities, nutrient availability, ordinary and inverse demand systems.

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Summary

Better understanding of quarterly meat demand will improve shortrun meat price and consumption forecasts and agricultural program analyses. This study estimates both ordinary (quantity-dependent) and inverse (price-dependent) quarterly demand systems for meats, in which price elasticity and flexibility estimates help in understanding the U.S. quarterly meat demand structure. Four types of meat are examined: high-quality (grain-fed) beef, manufacturing-grade (largely grass-fed) beef, pork, and broilers. Quarterly retail price and per capita disappearance data for 1970-90 are used for these meats. The estimated demand systems are then used to examine the empirical issues: the relationship between estimates of flexibilities and elasticities of meat demand, testing for structural change in meat demand, the implications of meat demand on nutrient availability for consumers, and the effects of meat quantity changes on meat prices and consumer welfare.

This study finds that the common practice of inverting an elasticity matrix to obtain measures of flexibilities can cause sizable differences from those estimated directly. Similarly, results found in comparing price elasticities from a directly estimated ordinary demand system with those from an inverted flexibility matrix are also problematical. This is because the elasticity and flexibility matrices obtained from any well-known estimation procedure are not the reciprocal of each other. Therefore, in agricultural policy and program analyses, the flexibilities from a directly estimated inverse demand system should be used to assess the price effects of quantity changes. To evaluate quantity effects of price changes, however, only elasticities from a directly estimated ordinary demand system should be used.

The question of whether there has been a structural change in the U.S. demand for meats has received much attention in recent years. To address the issue, this study develops a statistical procedure for testing the shifts of an entire set of demand parameters in the meat demand system over different periods. The results show no significant evidence of structural change in quarterly demand for meats between 1970-79 and 1980-90, by applying either an ordinary or an inverse demand system. Meat prices and expenditures, not shifts in consumer tastes, are the overwhelming factors determining the magnitude of change in quarterly meat consumption. On the other hand, quantities supplied are the major factors in changes in quarterly meat prices. The implication of this finding is that a decrease in meat prices through a reduction in production costs or improvements in marketing efficiency can be a very effective instrument in promoting meat consumption.

The issue of health and diet has become a major concern for consumers, and the National Nutrition Monitoring and Related Research Act was passed in 1990. This study explores the linkage of the determinants of food choice with consumer nutrient availability by developing a methodology to measure changes in nutrient availability as the demand for food items change. It uses demand elasticities from an ordinary demand system to infer the elasticities of change in the nutritional content of the diet. All 12 of the nutrients from meat studied (food energy, protein, fat, cholesterol, calcium, phosphorus, iron, potassium, sodium, thiamin, riboflavin, and niacin) are consumed in

increasing quantities when meat prices decline. Consumption of the 12 nutrients from meat is more sensitive to changes in prices of high-quality beef, less sensitive to pork price, and least sensitive to prices for broilers and manufacturing-grade beef. Nutrient consumption from meat also increases with per capita meat expenditures and income. These results are useful information to assess food program effects on the nutrient availability from meat to consumers.

Finally, given the interdependent nature of demands in consumers' budgeting, this study contributes a methodology for measuring consumer welfare by approximating the Hicksian compensating variation measure as a function of all price changes and compensated price elasticities obtained from estimated inverse and ordinary demand systems. The unique feature of this approach is that all direct- and cross-commodity effects are incorporated into price forecasting and the compensating variation measurement. The methodology is useful for developing an instrumental model to evaluate the effects of quantity changes on prices and consumer welfare. By applying to the U.S. meat sector, this study obtains simulation results showing that an increase of meat supplies in the domestic market would lower all meat prices and increase the economic well-being of consumers in terms of the amount of savings in meat expenditures. For example, a 1-percent increase in pork supplies translates to a $0.35-decline in quarterly per capita meat expenditures. This simulated change in meat expenditures could have significant effects on aggregate consumer welfare with quarterly savings of $87.5 million for the Nation.

U.S. Quarterly Demand for Meats

Kuo S. Huang and William F. Hahn

Introduction

Demand for meats is an important component of commodity analyses conducted in the Economic Research Service. To improve the efficiency of shortrun forecasts and program analyses, Stillman (*1985*), and Wescott and Hull (*1985*) estimated some quarterly econometric models for the U.S. meat sector to aid in situation and outlook analyses and related activities.[1] While these models are focused on specifying general demand-supply marketing behavioral relationships, the interdependent relationships of demand for meats are virtually unexplored. This study corrects the deficiencies of the previous works by using a demand system approach to measure the interdependencies of quarterly demand for meats. Both ordinary (quantity-dependent) and inverse (price-dependent) quarterly demand systems for meats are estimated.

The estimates of the ordinary and inverse demand systems can be applied to many empirical problems. In this report, these estimates are used to answer the following questions:

• What are the relationships between price elasticities and flexibilities of meat demand? The price elasticities defined as the percentage change in quantities demanded corresponding to given changes in prices, and price flexibilities, defined as the reverse, are widely used in economic analyses. Because of limited empirical estimates, it is a common practice to invert an elasticity for obtaining a flexibility measure or vice versa. To assess the reliability of this practice, this study compares the sizes of differences between a directly estimated meat demand matrix and a meat demand matrix obtained from matrix inversion.

• Have there been any structural changes in meat demand? The question of whether there has been a structural change in the U.S. demand for meats has received much attention in recent years, especially after a sharp decline in beef consumption and a steady increase in poultry consumption per person in the late 1970's. A statistical procedure is developed in this study for testing a shift of the entire set of demand parameters in a demand system over different periods. This procedure is then applied to test the structural change in meat demand.

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[1]Italicized numbers in parentheses identify year of publishing literature listed in the References at the end of this report.

• What are the nutritional implications of meat demand? Americans are increasingly concerned about their nutritional and health status. In 1990, the National Nutrition Monitoring and Related Research Act was passed. The act calls for a 10-year comprehensive plan to provide timely information about the role and status of factors that bear on the nutritional contribution to the health of Americans. An interagency board consisting of representatives from 22 Federal agencies coordinates the nutrition monitoring and related research activities. To provide information about the effects of economic factors on consumer nutritional status, this study develops a procedure to measure changes in nutrient availability as the demand for food items changes.

• What are the effects of meat quantity changes on meat prices and consumer welfare? In applied welfare analyses, it has been recognized that the use of the compensated demand curves leads to the appropriate welfare measures. Most of the methods available for measuring the Hicksian compensating variation, however, are restricted for use with a single price change. Given the interdependent nature of demands in consumers' budgeting, such a welfare analysis, is obviously not practical for empirical application. This study approximates the compensating variation measure as a function of all price changes and compensated price elasticities obtained from the estimated inverse and ordinary demand systems. In the process of welfare calculation, all potential direct- and cross-commodity effects are incorporated into the price forecasting and the welfare measurement.

Demand Model Specification

This study brings together ordinary (quantity-dependent) and inverse (price-dependent) demand models for the analysis of quarterly U.S. demand for meats. Both the demand models are theoretically consistent with utility-maximizing behavior on the part of consumers. As indicated by Hicks (*1956*, p.83), the Marshallian demands have two purposes: one is to show the amounts consumers will buy at given prices, and the other is to show the prices consumers will pay at given quantities. The price into quantity function defines an ordinary demand model, while the quantity into price function defines an inverse demand model. The ordinary and inverse demand models developed in Huang (*1988*, *1991* and *1993a*) are used in this study. The following is a brief discussion of model specification and parametric constraints that will be implemented in the empirical demand system estimation.

Ordinary Demand Model

Let q denote an n-coordinate column vector of quantities demanded for a "representative" consumer, p an n-coordinate column vector of the corresponding prices, $m = p.q$ the consumer expenditure which is the inner product of p and q, and $u(q)$ the utility function which is assumed quasi-concave in q. The primal function for maximizing consumer utility is the following Lagrangean function with multiplier π:

$$\underset{q,\pi}{\text{Maximize}}\ L = u(q) - \pi\ (p.q - m) \tag{1}$$

Defining $u_i(q)$ as the marginal utility of the ith commodity, the necessary conditions for an optimum are:

$$u_i(q) = \pi\ p_i \qquad i = 1,2,..,n \tag{2}$$

and $$p.q = m \tag{3}$$

In equation 2, π is known as the marginal utility of income showing the change in the maximized value of utility as income changes. The optimal conditions imply that the Hessian matrix defined as the second-order partial of $u(q)$, say $H = [u_{ij}(q) = \partial u^2/\partial q_i \partial q_j]$, is symmetric and negative definite.

A solution of equations 2 and 3 gives the ordinary demand system:

$$q_i = f_i(p,\ m) \qquad i = 1,2,..,n \tag{4}$$

While the utility structure is unknown, an ordinary demand model is obtained by applying the first-order differential approximation of the conceptual demand relationships as

$$dq_i = \mathbf{\Sigma}_j\ (\partial q_i/\partial p_j)\ dp_j + (\partial q_i/\partial m)\ dm \qquad i,j = 1,2,..,n \tag{5}$$

This demand system is quite general in relating to some small changes from any given point on the n-commodity demand surface.

By expressing the price and income slopes of equation 5 in terms of elasticities, a differential-form demand model is obtained as

$$dq_i/q_i = \mathbf{\Sigma}_j\ e_{ij}\ (dp_j/p_j) + \eta_i\ (dm/m) \qquad i,j = 1,2,..,n \tag{6}$$

where $e_{ij} = (\partial q_i/\partial p_j)(p_j/q_i)$ is a price elasticity of the ith commodity with respect to a price change of the jth commodity, and $\eta_i = (\partial q_i/\partial m)(m/q_i)$ is an expenditure (or income) elasticity showing the effect of the ith quantity in response to a change in per capita expenditure. This demand model is a general approximation of conceptual demand relationships without imposing any rigid functional form as does the logarithmic demand model.

To ensure theoretical consistency in applying the differential-form demand model, the following parametric constraints provided by the classical demand theory as that documented in Hicks (*1936*) should be applied:

Engel aggregation: $$\mathbf{\Sigma}_i\ w_i \eta_i = 1 \qquad i = 1,2,..,n \tag{7}$$

Homogeneity: $$\mathbf{\Sigma}_j\ e_{ij} + \eta_i = 0 \qquad i,j = 1,2,..,n \tag{8}$$

Symmetry: $$e_{ji}/w_i + \eta_j = e_{ij}/w_j + \eta_i \qquad i,j = 1,2,..,n \tag{9}$$

Negativity: $$e_{ii} + w_i\ \eta_i < 0 \qquad i = 1,2,..,n \tag{10}$$

Linkage condition: $e_{ij}* = e_{ij} + w_j \eta_i \qquad i,j = 1,2,..,n$ (11)

where $e_{ij}*$ is a compensated elasticity, and $w_i = p_i q_i/m$ is the expenditure weight of the *i*th commodity.

The Engel aggregation states that the sum of the expenditure elasticities weighted by the expenditure shares of corresponding commodities equals 1. The homogeneity condition implies that a consumer has no money illusion, and thus a proportional change in both price and expenditure leaves quantity demanded unchanged. The symmetry condition is derived from the symmetry of the Slutsky income compensated substitution terms. The negativity condition, derived from the diagonal entry of the Slutsky income compensated substitution terms, implies an increase in price with utility held constant must cause demand for that good to fall. Finally, the linkage condition is an expression of the Slutsky equation in terms of elasticities.

Inverse Demand Model

Within the same framework of utility maximization, an inverse demand system expressing prices as functions of quantities demanded and income can be derived as follows. Multiplying equation 2 by q_i and summing over n to satisfy the budget constraint, the Lagrange multiplier of the equation is expressed as

$$\pi = \Sigma_j q_j u_j(q)/m \qquad j = 1,2,..,n \tag{12}$$

Furthermore, substituting the Lagrange multiplier into equation 2 yields the following Hotelling-Wold identity (*1935, 1944*):

$$r_i = u_i(q)/ \Sigma_j q_j u_j(q) \qquad i,j = 1,2,..,n \tag{13}$$

where $r_i = p_i/m$ is the normalized price of the *i*th commodity, and $u_i(q)$ is the marginal utility of the *i*th commodity expressed as a function of a quantity vector q. Thus the identity is an inverse demand system, in which the normalized prices, defined as p_i/m, are functions of quantities demanded.

The inverse demand relationships can be explored by applying a distance function approach as follows. A distance function, say $d(u,q)$, is defined as a scale measure of the magnitude of the quantity vector q proportional to a reference quantity vector, say $q*$, which lies on the utility u; that is:

$$d(u,q) = q/q* \tag{14}$$

Since $q*$ yields u but is not necessarily the least cost at a price vector p, a cost function, say $c(u,p)$, can be expressed in the following inequality as

$$c(u,p) \leq (p.q*) \tag{15}$$

A multiplication of the distance function with the cost function yields:

$$d(u,q) = \min_{p} [(p.q)/c(u,p)] \tag{16}$$

Accordingly, the properties for the distance function as shown in Deaton (*1979*) can be obtained by working through the properties of the cost function. Having almost the same properties as the cost function, the distance function $d(u,q)$ is increasing in q, decreasing in u (the only difference), homogeneous of degree 1, and concave in q.

Because the cost function equals a fixed total expenditure (m) under an equilibrium condition, a compensated inverse demand function for the ith commodity is derived by differentiating the distance function with respect to q_i in accordance with the envelope theorem:

$$(r_i)_u = d_i(u,q) \qquad i = 1,2,..,n \tag{17}$$

This compensated inverse demand function is homogeneous of degree zero in q because of the linear homogeneity of the distance function. Also, from the concavity of a distance function, a Hessian matrix obtained as the second-order differential of $d(u,q)$ with respect to q, say $d_{ij}(u,q)$'s, is a symmetric and negative semidefinite matrix. The Hessian of the distance function is known as the Antonelli matrix (a counterpart of the Slutsky matrix), which describes the effect on the price that consumers are prepared to pay for one good resulting from a marginal increase of another good along the same indifference surface.

Based on equation 17, the compensated inverse demand function can be transformed into a set of demand relationships expressed in terms of price flexibilities as

$$f_{ij}^* = d_{ij}(u,q)\ (q_i\ q_j/w_i) \qquad i,j = 1,2,..,n \tag{18}$$

where $f_{ij}^* = (\partial r_i/\partial q_j^*)(q_j^*/r_i)$ is the compensated price flexibilities of the ith commodity with respect to a quantity change in the jth commodity, and w_i is the expenditure share of the ith commodity.

Since a distance function is homogeneous of degree zero in q, application of Euler's theorem yields the homogeneity condition for the compensated inverse demands as

$$\boldsymbol{\Sigma}_j\ f_{ij}^* = 0 \qquad i,j = 1,2,..,n \tag{19}$$

Moreover, from the properties of the Hessian matrix $[d_{ij}(u,q)\text{'s}]$, the following symmetry and negativity conditions of the compensated inverse demands are obtained:

$$f_{ji}^*/w_i = f_{ij}^*/w_j \qquad i,j = 1,2,..,n \tag{20}$$

$$f_{ii}^* < 0 \qquad i = 1,2,..,n \tag{21}$$

So far, some interdependent relationships of compensated inverse demands are known, but their relationships with uncompensated demands are still unspecified. Anderson (*1980*) filled this gap by separating the Antonelli matrix into components reflecting quantity and scale effects and obtained the following linkage equation between compensated and uncompensated price flexibilities:

$$f_{ij}^* = f_{ij} - g_i\, w_j \qquad i,j = 1,2,..,n \tag{22}$$

where $f_{ij} = (\partial r_i/\partial q_j)(q_j/r_i)$ is the uncompensated price flexibility of the ith commodity with respect to a quantity change in the jth commodity, and $g_i = (\partial r_i/\partial s)(s/r_i)$ is the scale flexibility showing the effect of the ith price in response to a proportional change with a scale s in all quantities demanded. Using this linkage equation and homogeneity condition, one can derive a scale aggregation through the budget constraint as

$$\Sigma_i\, w_i\, g_i = -1 \qquad i = 1,2,..,n \tag{23}$$

To specify an empirical inverse demand model, this study defines the scale variable s as the geometric expenditure-weighted average of individual quantities q_j's; that is, $\log s = \Sigma_j\, w_j \log q_j$. Then using the scale variable to deflate a quantity vector q, a reference quantity vector $q^* = q/s$ is obtained. Thus the Hotelling-Wold identity can be expressed as a function of q^* and s. Where the consumer utility structure is unknown, the identity is approximated in a general form by relating changes from any given point on the n-commodity demand surface as

$$dr_i = \Sigma_j\, (\partial r_i/\partial q_j^*)\, dq_j^* + (\partial r_i/\partial s)\, ds \qquad i,j = 1,2,..,n \tag{24}$$

By expressing the quantity and scale quantity slopes of the above equation 24 in terms of compensated price and scale flexibilities, the following differential-form inverse demand model is derived as

$$dr_i/r_i = \Sigma_j\, f_{ij}^*\, (dq_j^*/q_j^*) + g_i\, (ds/s) \qquad i,j = 1,2,..,n \tag{25}$$

The flexibility constraints applicable to this demand model are summarized as

Scale aggregation:	$\Sigma_i\, w_i\, g_i = -1$	$i = 1,2,..,n$	(26)
Homogeneity:	$\Sigma_j\, f_{ij}^* = 0$	$i,j = 1,2,..,n$	(27)
Symmetry:	$f_{ji}^*/w_i = f_{ij}^*/w_j$	$i,j = 1,2,..,n$	(28)
Negativity:	$f_{ii}^* < 0$	$i = 1,2,..,n$	(29)
Linkage condition:	$f_{ij}^* = f_{ij} - g_i\, w_j$	$i,j = 1,2,..,n$	(30)

Furthermore, as shown in Huang (*1994a*), the application of a distance function approach to derive a compensated inverse demand model is theoretically equivalent to the Houck's (*1966*) uncompensated inverse demand model. By substituting uncompensated for compensated price flexibilities through the linkage equation 30 and applying the homogeneity condition of equation 27, the uncompensated inverse demand model is derived as

$$dr_i/r_i = \Sigma_j f_{ij} (dq_j/q_j) + g_i [ds/s - \Sigma_j w_j (dq_j/q_j)]$$

$$= \Sigma_j f_{ij} (dq_j/q_j) \qquad i,j = 1,2,..,n \qquad (31)$$

This is a differential-form uncompensated inverse demand model, which can be obtained alternatively by a direct approximation of the Hotelling-Wold identity of equation 13.

The parametric constraint of the uncompensated inverse demand model can be derived as follows. By incorporating the symmetry condition of equation 28 and the scale aggregation of equation 26 into linkage equation 30, a parametric constraint is obtained:

$$f_{ij} = f_{ij}^* + g_i w_j$$

$$= (w_j/w_i) f_{ji}^* + g_i w_j$$

$$= (w_j/w_i)(f_{ji} - g_j w_i) + g_i w_j$$

$$= (w_j/w_i)f_{ji} - w_j (\Sigma_h f_{jh} - \Sigma_h f_{ih}) \qquad i,j,h = 1,2,..,n \qquad (32)$$

This constrained relationship coincides with the Houck's symmetric constraint, in which Houck worked on a flexibility matrix implied by the constraints on an elasticity matrix derived from the classical demand theory framework. It is interesting to note that since Houck's article, which was published in 1966, there has been little evidence of any implementation of his model in demand system estimation. The symmetric constraint of equation 32 is the only parametric constraint applicable to the uncompensated inverse demand model (equation 31). All income flexibilities implied by the Hotelling-Wold identity are implicitly constrained to unitary values; that is, for given quantities demanded, an increase in income will cause each commodity price to increase at the same rate.

Empirical Model Specification

For modeling quarterly demand for meats in this study, some empirical considerations are required to modify the above conceptual demand models. By applying the differential-form ordinary demand model of equation 6, an empirical demand system consisting of n commodities can be specified as a set of n linear equations as follows:

$$q_1' = \Sigma_j e_{1j} p_j' + \eta_1 m' + \delta_1 + \delta_{12} d_2 + \delta_{13} d_3 + \delta_{14} d_4$$

$$\vdots$$

$$q_n' = \Sigma_j e_{nj} p_j' + \eta_n m' + \delta_n + \delta_{n2} d_2 + \delta_{n3} d_3 + \delta_{n4} d_4 \qquad (33)$$

where variables q_i', p_i', and m' are the relative changes in quantity, price, and per capita expenditure. The variable at time t, for example, quantity q_i' is defined as the first-order differential form $(q_{i,t} - q_{i,t-1})/q_{i,t-1}$. The parameters e_{ij} and η_i are price and expenditure elasticities, δ_i is a constant, and δ_{i2}, δ_{i3}, and δ_{i4} are coefficients associated with the dummy variables d_2, d_3, and d_4 assigned for second, third, and fourth seasons. Consequently, the intercept estimate in each meat demand equation should be interpreted as a time trend, while estimates with dummy variables represent seasonal shifters in the time trend.

To ensure internal consistency with the demand structure provided by the classical demand theory, the parametric constraints of symmetry ($e_{ji}/w_i + \eta_j = e_{ij}/w_j + \eta_i$), homogeneity ($\Sigma_j\ e_{ij} + \eta_i = 0$), and Engel aggregation ($\Sigma_i\ w_i\eta_i = 1$) are incorporated into estimation by applying constrained maximum likelihood estimation. The incorporation of the constraints makes it possible to reduce about half of the total number of demand parameters in the demand model from direct estimation and thus alleviates the potential multicollinearity problem in estimation. The negativity condition, however, is not incorporated, partly because there is no reduction in the number of parameters to be estimated and, thus, no gain in asymptotic efficiency of the estimates, and partly to avoid introducing parametric inequality constraints that would increase the complexity of estimation.

The validity of applying these theoretical constraints in empirical work has been tested in some studies. As discussed in Deaton and Muellbauer (*1980*, p. 74), however, the test results can hardly distinguish whether the hypothesis is false, whether the approximation of the demand system is inaccurate, or whether the aggregate data apparently used in most empirical studies are not adequate to relate the individual consumer behavior from which the theory is derived. Thus, while the main purpose of introducing the prior constrained information is to improve the efficiency of estimates, this study does not test the theory.

On fitting an empirical compensated inverse demand system, the demand system can be specified as

$$
\begin{aligned}
r_1' &= \Sigma_j\ f_{1j}^*\ q_j'' + g_1\ s + \delta_1 + \delta_{12}\ d_2 + \delta_{13}\ d_3 + \delta_{14}\ d_4 \\
&\ \ \vdots \\
r_n' &= \Sigma_j\ f_{nj}^*\ q_j'' + g_n\ s + \delta_n + \delta_{n2}\ d_2 + \delta_{n3}\ d_3 + \delta_{n4}\ d_4 \qquad (34)
\end{aligned}
$$

where variables r_i' and q_i'' are the relative changes in normalized price and reference quantity, and f_{ij}^* and g_i are compensated price and scale flexibilities. Dummy variables are defined the same as in equation 33. The parametric constraints of symmetry ($f_{ji}^*/w_i = f_{ij}^*/w_j$), homogeneity ($\Sigma_j\ f_{ij}^* = 0$), and scale aggregation ($\Sigma_i\ w_i g_i = -1$) should be incorporated into the estimation. Again, the negativity condition is not incorporated into estimation.

Similarly, on fitting an empirical uncompensated inverse demand system, the demand system can be specified as:

$$r_1' = \boldsymbol{\Sigma}_j f_{1j} q_j' + \delta_1 + \delta_{12} d_2 + \delta_{13} d_3 + \delta_{14} d_4$$

$$\vdots$$

$$r_n' = \boldsymbol{\Sigma}_j f_{nj} q_j' + \delta_n + \delta_{n2} d_2 + \delta_{n3} d_3 + \delta_{n4} d_4 \qquad (35)$$

where variables r_i' and q_i' are the relative changes in normalized price and quantity, and f_{ij} is an uncompensated price flexibility. Dummy variables are defined the same as in equation 33. Only the parametric constraints of symmetry $[f_{ij} = (w_j/w_i)f_{ji} - w_j (\boldsymbol{\Sigma}_h f_{jh} - \boldsymbol{\Sigma}_h f_{ih})]$ should be incorporated into the estimation of this demand system.

In empirical estimation of any of the demand systems above, either price (in ordinary demand) or quantity (in inverse demand) is implicitly assumed to be an exogenous variable. Potential simultaneity between prices and quantities, though important in marketing equilibrium analysis, is not addressed here because the issue is difficult to treat when estimating a complete demand system with parametric constraints across equations. The price elasticities and flexibilities in both the demand systems are assumed to be fixed demand parameters. The assumption may be too strong, because restrictions are thereby placed on the implied utility structure.

Nevertheless, the constant demand parameter assumption is useful in empirical application. First, the demand parameters can be directly interpreted as price elasticities or flexibilities, which are widely used by applied economists. Although other demand models such as the Rotterdam, the AIDS (Almost Ideal Demand System), and the translog models are capable of generating elasticities, the generated demand elasticities may be unstable inasmuch as they are functions of expenditure shares, which are stochastic variables in these models. Second, the resulting demand model is linearized in parameters, and the computational burden is reduced considerably. Third, the dependent variable defined as the relative change of quantities or normalized prices is easily quantified by using available data usually expressed in index numbers. Other demand models similar to the direct translog model or the Rotterdam model require the time series data of expenditure shares (which are not available in many food demand studies) as dependent variables in the models.

Estimation Results and Applications

Both the differential-form ordinary and inverse demand models specified in the Demand Model Specification section are applied to estimate U.S. quarterly meat demand. Because of limited quarterly price and quantity data for all foods, this study focuses on meats by estimating a demand model conditionally on the allocation of meat expenditures. Thus, special caution is required to interpret the estimation results as the consumer response in allocating a given meat expenditure but not total consumption expenditure as in a general food demand system. The use of conditional demand structure is consistent with much of the previously applied studies on the demand for meats, such as in Christensen and Manser (*1977*), and Moschini and Meilke (*1989*). Also, Alston and Chalfant's (*1990*) nonparametric tests suggest that U.S. meat consumption is separable from the consumption of other goods.

Data used in this study are quarterly disappearance of U.S. meat quantities and retail prices compiled from 1970 to 1990. The retail choice beef price is used for the price of high-quality beef, and the regular ground beef price for the retail price of manufacturing-grade beef. The data on the slaughter of cattle by classes are used to split beef production into high-quality and manufacturing-grade beef. Grain-fed animal slaughter determines high-quality beef production. Grass-fed cattle slaughter determines the production of manufacturing-grade beef. All U.S. imports are assumed to be manufacturing-grade beef and all exports are high-quality beef. On average in the sample period, 50.54 percent of meat expenditure was for high-quality beef, 9.61 percent for manufacturing-grade beef, 29.43 percent for pork, and 10.42 percent for broilers.

Table 1 illustrates the recent trends in U.S. meat production, consumption, and trade using yearly average data. The United States is the world's largest importer of beef. The bulk of this beef is manufacturing-grade beef from Australia and New Zealand. This beef is generally mixed with higher-fat trimmings to produce hamburger or other ground products. The United States is a growing exporter of high-quality beef. Beef exports increased from 0.54 percent of production in the 1970's to 3.28 percent in the late 1980's. Japan is the most important beef customer, taking more than 50 percent of all U.S. beef exports.

Since the 1970's, the United States has been among the world's largest pork importers as well. Pork imports more than doubled between the beginning of the 1970's and the end of the 1980's. In 1990, the most important sources of pork were Canada, Denmark, and Poland. Because of low feed costs and highly efficient production facilities, the United States was also the world's largest chicken meat exporter in 1990. Chicken (mainly broiler) meat exports increased more than seven-fold between the beginning of the 1970's and the end of the 1980's. Major export markets have varied over the years. The major buyers of U.S. chicken meat in 1971-90 included Japan, Hong Kong, Mexico, the Soviet Union, and Canada.

In this section, in addition to presenting demand parameter estimates, the major focus is on applying the estimated demand systems to examine the

Table 1--U.S. meat production, consumption, and trade (yearly average)

Period	1971-75	1976-80	1981-85	1986-90
Beef:		Million pounds		
Imports	1,811	2,156	1,910	2,262
Exports	120	137	276	765
Consumption	24,230	25,686	24,690	24,914
Production	22,541	23,716	23,099	23,471
		Percent		
Imports/consumption	7.50	8.45	7.73	9.09
Exports/production	0.54	0.59	1.19	3.28
Pork:		Million pounds		
Imports	499	491	788	1,049
Exports	247	288	207	178
Consumption	14,222	14,330	15,451	15,793
Production	13,952	14,279	14,984	15,057
		Percent		
Imports/consumption	3.53	3.44	5.10	6.67
Exports/production	1.82	2.05	1.37	1.17
Chicken:		Million pounds		
Exports	117	418	522	829
Consumption	8,567	10,377	12,695	16,037
Production	8,780	10,944	13,371	17,047
		Percent		
Exports/production	1.33	3.78	3.94	4.81

Note: Compiled from Putnam, J.J., and J.E. Allshouse (1992).

empirical issues of the relationship between estimates of flexibilities and elasticities of meat demand, testing for structural change in meat demand, the implications of meat demand on nutrient availability of consumers, and the effects of meat quantity changes on meat prices and consumer welfare.

Elasticities versus Flexibilities

The price elasticities and flexibilities are widely used in economic analyses. To reflect that quantities and income are given in farm market demand relationships with price adjustments providing the market-clearing mechanism, agricultural economists often use flexibility measures for making agricultural pricing decisions. Because of limited empirical flexibility estimates, some agricultural economists take the reciprocal of a directly estimated elasticity or, more rigorously, the inverse of an elasticity matrix at the retail level, as flexibility measures (for example, Wohlgenant, *1989*, and Young, *1990*). They then shift the model to the farm level using price transmission or markup equations. The question is whether inverting a matrix of directly estimated elasticities can represent flexibilities for empirical application.

Taking the reciprocal of an elasticity estimate in a single demand equation yields a different flexibility estimate from direct estimation. Similarly, inverting a matrix of elasticities to obtain measures of flexibilities would not lead to the same figures as would estimating flexibilities directly. Thus far, only Huang (*1994a*) has illustrated explicitly the differences between directly estimating flexibilities and inverting an elasticity matrix. This study uses the results of that article to examine the relationships of price elasticities and price flexibilities by comparing the sizes of the difference between a directly estimated demand matrix and an inverted demand matrix.

The estimates of uncompensated price elasticities obtained from an ordinary demand model (equation 33) with seasonal dummy variables are presented in case (*A*) of table 2. The quarterly demand for high-quality beef and pork is relatively elastic (with direct-price elasticities of -1.0364 and -0.8379), while elasticities for manufacturing-grade beef and broilers are low (-0.4006 and -0.1969). The constant term in each demand equation may reflect the potential time trends of demand for meats. Most estimated constants are not statistically significant, except for broilers, whose positive intercept estimate implies increasing consumption over the sample period.

An uncompensated inverse demand model (equation 35) with seasonal dummy variables is applied to provide a direct comparison of uncompensated elasticities. The estimated uncompensated price flexibilities are presented in case (*B*) of table 2. Direct-price flexibilities are -0.6326 (high-quality beef), -0.2245 (manufacturing-grade beef), -0.8032 (pork), and -0.7769 (broilers). The same demand model without seasonal dummy variables is also estimated to examine the sensitivity of alternative model specifications; these estimation results are presented in case (*C*) of table 2. Direct-price flexibilities are -0.6183 (high-quality beef), -0.2518 (manufacturing-grade beef), -0.4690 (pork), and -0.4020 (broilers). The flexibility estimates in cases (*B*) and (*C*) have the correct sign, and their magnitudes are close for both beef products.

To assess the performance of the estimated demand systems, the relative root-mean-square errors to sample means (*RMS*) expressed in percentage terms are computed as

$$RMS = [\boldsymbol{\Sigma}_t(y_t - \hat{y}_t)^2/T]^{\frac{1}{2}} \;/\; \bar{y} \quad \text{x } 100 \qquad t = 1,..,T \tag{36}$$

where y_t, $\hat{y}_t$, and $\bar{y}$ are the respective levels of actual, simulated, and sample mean of per capita consumption (in the ordinary demand system) or normalized price (in the inverse demand system) for a sample period of T observations. The *RMS* of the estimated demand systems are computed and reported in table 2 with the *RMS* being less than 8 percent in each demand equation. Graphic presentation of the actual and simulated results obtained from cases (*A*) and (*B*) are presented in the appendix to confirm the precision of model fitting and provide a better comprehension of simulation performance.

The common measures of R^2 and Durbin-Watson (*DW*) statistics of each demand equation are also computed and reported in the last column of the table. As expected, R^2 magnitudes are reversely related to *RMS* errors. Estimated *DW* statistics show the equations are free of serial correlation in most cases.

Table 2--Directly estimated uncompensated elasticities and flexibilities

	Beefh	Beefm	Pork	Broiler	Meat-exp	Constant	D2	D3	D4	RMS	R^2/DW
Quantity: Case (A) Estimated elasticities										Percent	
Beefh	-1.0364	-0.1497	-0.1949	-0.1352	1.5162	0.0348	-0.0216	-0.0420	-0.0739	1.67	0.90
	(0.0723)	(0.0401)	(0.0385)	(0.0193)	(0.0721)	(0.0041)	(0.0055)	(0.0062)	(0.0056)		2.56
Beefm	0.1146	-0.4006	0.4814	0.0737	-0.2691	-0.0459	0.0311	0.0942	0.0649	7.56	0.38
	(0.2576)	(0.1887)	(0.1459)	(0.0724)	(0.3226)	(0.0178)	(0.0239)	(0.0265)	(0.0242)		2.52
Pork	-0.0141	0.0465	-0.8379	-0.0765	0.8819	-0.0412	0.0057	0.0431	0.1304	2.09	0.92
	(0.0770)	(0.0412)	(0.0538)	(0.0232)	(0.0934)	(0.0052)	(0.0069)	(0.0080)	(0.0070)		2.24
Broiler	0.1106	0.0420	0.0435	-0.1969	0.0008	0.0247	0.0500	-0.0245	-0.0846	2.70	0.78
	(0.1104)	(0.0636)	(0.0691)	(0.0548)	(0.1216)	(0.0067)	(0.0090)	(0.0103)	(0.0092)		1.94
Price: Case (B) Estimated flexibilities											
Beefh	-0.6326	-0.1077	-0.0359	-0.0135	1.0000	0.0190	-0.0077	-0.0252	-0.0373	1.32	0.87
	(0.0361)	(0.0168)	(0.0345)	(0.0294)		(0.0036)	(0.0048)	(0.0049)	(0.0067)		2.07
Beefm	-0.5643	-0.2245	-0.0153	-0.0115	1.0000	0.0155	-0.0075	-0.0257	-0.0271	3.80	0.45
	(0.0959)	(0.0572)	(0.0789)	(0.0660)		(0.0100)	(0.0130)	(0.0146)	(0.0173)		1.36
Pork	-0.2129	-0.0242	-0.8032	-0.0487	1.0000	-0.0300	-0.0005	0.0410	0.0937	1.92	0.83
	(0.0543)	(0.0235)	(0.0525)	(0.0430)		(0.0054)	(0.0067)	(0.0071)	(0.0110)		1.89
Broiler	-0.6129	-0.1151	-0.3682	-0.7769	1.0000	0.0137	0.0346	0.0097	-0.0721	4.41	0.50
	(0.1211)	(0.0629)	(0.1152)	(0.1731)		(0.0131)	(0.0170)	(0.0177)	(0.0275)		1.84
Price: Case (C) Estimated flexibilities (model without dummy variables)											
Beefh	-0.6183	-0.1282	-0.1681	-0.0032	1.0000	0.0016				1.63	0.73
	(0.0383)	(0.0141)	(0.0275)	(0.0244)		(0.0017)					1.89
Beefm	-0.6754	-0.2518	0.0142	-0.0067	1.0000	0.0001				3.89	0.48
	(0.0888)	(0.0461)	(0.0609)	(0.0520)		(0.0042)					1.45
Pork	-0.3385	-0.0047	-0.4690	-0.2045	1.0000	0.0043				2.82	0.52
	(0.0625)	(0.0188)	(0.0435)	(0.0249)		(0.0029)					1.48
Broiler	-0.2770	-0.0557	-0.7003	-0.4020	1.0000	0.0043				4.67	0.54
	(0.1116)	(0.0490)	(0.0799)	(0.1055)		(0.0052)					1.69

Note: The abbreviated notations are Beefh (high-quality beef), Beefm (manufacturing-grade beef), Meat-exp (Meat expenditure), RMS (relative root-mean-square errors to sample means), DW (Durbin-Watson statistic), and D2, D3, and D4 seasonal dummy variables assigned for second, third, and fourth seasons. Figures in parentheses are the estimated standard errors. Case (C) does not have dummy variables D2, D3, and D4.

These R^2 and *DW* diagnostic statistics, however, do not directly apply to the present demand systems, in which variables are expressed in the first-order differential form and all equations are simultaneously estimated through the incorporation of parametric constraints across equations.

Table 3 shows inverted elasticity and flexibility matrices obtained from table 2. The figures in case (*A*) of table 3 are inverted price flexibilities obtained by inverting the matrix of directly estimating price elasticities in case (*A*) of table 2. The figures in cases (*B*) and (*C*) of table 3 are inverted price elasticities obtained by inverting the matrices of directly estimating price flexibilities in cases (*B*) and (*C*) of table 2. The results show that

Table 3--Inverted uncompensated elasticities and flexibilities

	Beefh	Beefm	Pork	Broiler
Price:	Case (A) Inverted flexibilities			
Beefh	-0.8623	0.4378	0.4816	0.5688
Beefm	-0.2882	-2.5762	-1.4241	-0.2131
Pork	0.0474	-0.1202	-1.2523	0.4090
Broiler	-0.5354	-0.3302	-0.3099	-4.7143
Quantity:	Case (B) Inverted elasticities			
Beefh	-2.8418	1.3373	0.1430	0.0206
Beefm	7.1269	-7.8331	-0.4779	-0.0221
Pork	0.4804	-0.1286	-1.3034	0.0753
Broiler	0.9584	0.1664	0.5757	-1.3424
Quantity:	Case (C) Inverted elasticities (model without dummy variables)			
Beefh	7.0995	-4.6807	-11.3074	5.7737
Beefm	-20.7135	9.5823	32.0558	-16.3018
Pork	-16.7831	10.2111	17.6657	-9.0232
Broiler	27.2149	-15.8906	-27.4244	11.5116

Note: The demand parameters in cases (A), (B), and (C) are generated from demand matrices in table 2. The abbreviated notations are Beefh (high-quality beef) and Beefm (manufacturing-grade beef).

inverting a matrix of elasticities to obtain measures of flexibilities or vice versa does not lead to the same figures as those estimated directly. For example, the direct-price elasticities in case (*A*) of table 2 are significantly different from the inverted direct-price elasticities in cases (*B*) and (*C*) of table 3. In particular, all the inverted direct-price elasticities in case (*C*) have wrong signs, despite the fact that the inverted results in cases (*B*) and (*C*) are derived from similar directly estimated flexibility matrices in table 2, one with and the other without, including seasonal dummy variables. Similarly, most of the inverted direct-price flexibilities in case (*A*) of table 3 are significantly different from the directly estimated flexibilities in cases (*B*) and (*C*) of table 2.

As discussed in Huang (*1990*), elasticity and flexibility matrices obtained from any well-known estimation procedure are not the reciprocal of each other. First, in the estimation of an ordinary demand system, the sum of residuals is minimized along the quantity axis, whereas the sum of residuals is minimized along the price axis in the estimation of an inverse demand system. Second, by inverting a demand matrix, one ignores the stochastic nature of the statistical estimates and treats the point estimates of the demand parameters as exact numbers. Third, the inverted results are quite sensitive to the numerical structure of a demand matrix being inverted, and that could cause unstable results.

The results in this study show that by using the inverted elasticities to represent flexibilities or vice versa, sizable differences in measurement are made. Therefore, it is not proper to use the inverted elasticity or flexibility measurements in agricultural policy and program analyses. Consistent with Waugh's (*1964*, pp. 29-30) view, the flexibilities from a directly estimated inverse demand system should be used to assess the price effects of quantity changes. To evaluate quantity effects of price changes, however, only elasticities from a directly estimated ordinary demand system should be used.

Testing for Demand Structural Change

The question of whether there has been a structural change in the U.S. demand for meats has received much attention in recent years, especially after a sharp decline in beef consumption and a steady increase in poultry meat consumption per person in the late 1970's. To the meat industry decision-makers, the issue of structural change is important for their production plans and marketing strategies. They need to determine whether to scale down the size of cattle herds or spend more money for meat promotion programs.

Many economists such as Nyankori and Miller (*1982*), Chavas (*1983*), and Moschini and Meilke (*1989*) applied an ordinary (quantity-dependent) demand system to test the structural change in meat demand and obtained mixed results. For analysis of quarterly meat demand as in this study, an inverse (price-dependent) demand system is probably the most appropriate model for testing structural change in meat demand. This is because meat production and consumption within a quarter are largely determined by farmers' marketings of animals. While animal production decisions are made well in advance of marketings, for example, beef takes approximately 27 months from breeding until slaughter weight. Consequently, meat production and consumption for a quarter are likely to be predetermined.

A structural change in meat demand may be viewed as a shift of the entire set of demand parameters including direct- and cross-commodity effects in a demand system over different periods. For a convenient illustration of the testing procedure developed in Huang (*1994b*), let us first consider a demand system without a constant term and dummy variables. The testing procedure can be formulated by extending Chow's (*1960*) test in two linear regressions to a set of n demand equations with parameters constrained across equations. The following is a brief explanation about how to formulate a testing statistic on the basis of demand system estimation.

In this study, given a compensated inverse demand system similar to the one expressed in equation 25, the stochastic specification for T sample observations can be represented in an abbreviated Kronecker product form as

$$y = (I_n \otimes X)\ \alpha + u \tag{37}$$

y = column vector of n x T observations, obtained by stacking the relative change in the normalized price of each equation in the system,
I_n = n x n identity matrix,
X = T x $(n+1)$ matrix containing the observations of the relative change in all the reference and scale quantities,
α = column vector of all $n(n+1)$ demand parameters, obtained by stacking the parameters of each equation, and
u = column vector of n x T random disturbances.

Using the scale aggregation condition (equation 26), the scale flexibility of the nth commodity can be expressed as a function of the scale flexibilities of all other commodities as

$$g_n = -1/w_n - \Sigma_i w_i g_i/w_n \tag{38}$$

The symmetry conditions (equation 28) permit the representation of $n(n-1)/2$ cross-price flexibilities as:

$$f_{ji}^* = (w_i/w_j)\ f_{ij}^* \qquad j = 2,3,..,n;\ i = 1,2,..,(j-1) \tag{39}$$

Finally, the homogeneity constraints (equation 27), with the other conditions, lead to the expressions of n direct-price flexibilities as follows:

$$f_{ii}^* = -\ \Sigma_j\ (w_j/w_i)\ f_{ji}^* - \Sigma_k\ f_{ik}^* \qquad i = 1,2,..,(n-1);\ j = 1,2,..,(i-1);\ k = i+1,i+2,..,n \tag{40}$$

$$f_{nn}^* = -\ \Sigma_j\ (w_j/w_n)\ f_{jn}^* \qquad j = 1,2,..,(n-1) \tag{41}$$

The parametric constraints shown in equations 38 to 41 can be expressed in matrix form as

$$\alpha = R\beta + h \tag{42}$$

α = column vector of all $n(n+1)$ parameters obtained by stacking the parameters of each equation,
β = column vector of $[n(n+1)/2 - 1]$ parameters appearing on the right-hand side of equations 38 to 41,
R = $n(n+1)$ x $[n(n+1)/2 - 1]$ matrix of constraints, and
h = fixed vector of $n(n+1)$ entries.

The system of demand equations (equation 37) can be estimated by incorporating the parametric constraints of equation 42 as

$$y^* = (I_n \otimes X)\ R\ \beta + u \tag{43}$$

where $y^* = y - (I_n \otimes X)\ h$. Note that, of the total $n(n+1)$ demand parameters in α, only $[n(n+1)/2 - 1]$ demand parameters in β are required to be estimated directly. Thus, the new statistical model (equation 43), which reduces by more than half the total number of demand parameters, not only saves much computation time, but also alleviates the potential multicollinearity problem and improves the statistical efficiency of estimates.

Suppose that the random disturbances at time t, say $u_t = (u_{1t},.., u_{nt})'$, are distributed according to a multivariate normal $N(0,\Omega)$. The disturbances of each equation are assumed to be homoscedastic and uncorrelated. Also, the disturbances in different equations are assumed to be pairwise correlated for the same t (but not for the different t) with a constant covariance. Then the maximization of the likelihood function for T observations is equivalent to the maximization of the following equation:

$$L(\beta) = - u' (\Omega^{-1} \otimes I_T) u \tag{44}$$

where $u = y* - (I_n \otimes X) R \beta$

By differentiating $L(\beta)$ with respect to β and then setting it equal to zero, a set of normal equations can be obtained as

$$R' (\Omega^{-1} \otimes X') [y* - (I_n \otimes X) R \beta] = 0 \tag{45}$$

Given a prior consistent estimate of Ω, say $\hat{\Omega}$, the consistent estimate of β is then:

$$\hat{\beta} = [R' (\hat{\Omega}^{-1} \otimes X'X) R]^{-1} [R' (\hat{\Omega}^{-1} \otimes X') y*] \tag{46}$$

Since the estimate of the covariance matrix for disturbances provided by ordinary least squares of the unconstrained model is consistent, this estimate, say $\hat{\Omega}$, may be used to obtain $\hat{\beta}$. The covariance of $\hat{\beta}$ is then approximated by:

$$\hat{\Omega}_{\beta} = [R' (\hat{\Omega}^{-1} \otimes X'X) R]^{-1} \tag{47}$$

The constrained maximum likelihood method is one way to derive parameter estimates that can be used to test for structural change in demand. Since the demand system is estimated by incorporating the parametric constraints of homogeneity, symmetry, and scale aggregation, the number of directly estimated demand parameters is only about half of the total number of demand parameters. That is, while there is a total of $n(n+1)$ demand parameters, the full set can be calculated from a subset containing only $n(n+1)/2-1$. Accordingly, a constrained demand system can be estimated first by using a set of T observations, and then a vector of estimated residuals by stacking each equation, say ϵ, is computed. The sum of squares of estimated residuals is then computed as $A = \epsilon'(\Omega^{-1} \otimes I_T)\epsilon$, which is a chi-square distribution with degrees of freedom $nT-n(n+1)/2+1$.

For testing the demand structural change between two periods, the whole sample period T is divided into T_1 and T_2 observations to reflect potential demand structural change. The constrained demand system estimation is performed for each period separately, and the estimated residual vectors, ϵ_1 and ϵ_2, are obtained respectively. Then, the sum of squares of estimated residuals for these two demand subsystems is computed as $B = \epsilon_1'(\Omega_1^{-1} \otimes I_{T1})\epsilon_1 + \epsilon_2'(\Omega_2^{-1} \otimes I_{T2})\epsilon_2$, which is a chi-square distribution with degrees of freedom $nT-n(n+1)+2$.

Similar to Theil's (*1971*, p. 312-317) testing procedure for linear constraints on coefficient of different equations, this study uses the residual measures A and B and formulates the following F-statistic with k degrees of freedom in the numerator and $(nT-2k)$ in the denominator:

$$F = [(A-B)/k] \,/\, [B/(nT-2k)] \sim F(k,\ nT-2k) \tag{48}$$

where $k = n(n+1)/2-1$. This F-statistic can be used to test a null hypothesis about the equality of two sets of demand parameters. If the F-statistic is larger than a critical value at a certain significant level, the null hypothesis about no structural change should be rejected. Otherwise, the null hypothesis should be accepted if the F-statistic is less than the critical value.

To test the structural change in U.S. meat demand after a volatile change in meat consumption in the late 1970's, the sample observations are split into the two periods (1970-79 and 1980-90), and demand systems for periods 1970-79, 1980-90, and 1970-90 are then estimated respectively. Estimation results of quarterly compensated inverse demand systems with a constant term and seasonal dummy variables are presented in table 4. Most estimates are statistically significant, and the signs of all compensated direct-price and scale flexibilities are negative as expected. Among estimates, the direct-price flexibilities in 1970-79 are high-quality beef (-0.3529), manufacturing-grade beef (-0.1730), pork (-0.5054), and broilers (-1.3346). These price flexibilities of high-quality beef and broilers are slightly higher in absolute value than those in 1980-90, and the price flexibilities of manufacturing-grade beef and pork are close. The individual parameter comparison, however, can hardly detect any structural change in demand, because the information about a significant shift of the entire set of parameters is required.

To formulate F-statistic for testing the potential structural change in meat demand, the sum of squares of residuals for each of the three demand systems in association with different periods is computed. For an empirical demand system as implemented in this study with a constant term and seasonal dummy variables, the k value in the F-statistic should be $n(n+9)/2-1$. Since variables are defined as relative change with an initial observation to serve as a base measurement, the total number of observations in model estimation T equals 83 covering the second quarter of 1970 to the fourth quarter of 1990. On the basis of equation 48, replacing the unknown Ω^{-1} by $\hat{\Omega}^{-1}$ as implemented in equation 46, the computed value of the F-statistic is 0.58 with degrees of freedom $k = 25$ and $nT-2k = 282$. By comparing this F-statistic with available critical values in statistical table having $F(24, 200) = 1.57$ and $F(24, 400) = 1.54$ at 5-percent significance, the F-statistic is clearly less than the least critical value. Thus the null hypothesis about the equality between two sets of demand parameters cannot be rejected, implying no demand structural change between periods 1970-79 and 1980-90.

The implication of this finding is that meat quantities supplied, instead of shifts in consumers' taste, are responsible for changes in meat prices over the two concerned periods. The evidence of no structural change in meat demand is enhanced in a graphic comparison of actual and simulated prices in the appendix figures 5 to 8. In these figures, meat quantities explain well the movement of meat prices over time; their computed relative root-mean-square (*RMS*) errors to sample means of simulation range from 1.31 to 4.42 percent. In particular, the major part of the large increase in normalized prices of both types of beef in 1979 is clearly attributable to the effect of quantity changes. These results are consistent with the finding in Eales and Unnevehr's (*1993*) work. They applied the AIDS model to test structural change in meat demand and concluded that the abrupt demand shift, particularly the post-1975 beef decline, is an artifact of supply-side shocks manifesting themselves through endogenous prices.

Table 4--Testing structural change based on compensated inverse demand system

Price	Beefh	Beefm	Pork	Broilers	Scale	D2	D3	D4	Constant	RMS	R^2/DW
	Case (A) Price flexibilities for the first period, 1970-79									Percent	
Beefh	-0.3529	-0.0358	0.1842	0.2046	-0.6949	-0.0238	-0.0228	-0.0251	0.0195	1.55	0.88
	(0.0616)	(0.0199)	(0.0364)	(0.0436)	(0.1058)	(0.0085)	(0.0082)	(0.0101)	(0.0058)		2.11
Beefm	-0.1885	-0.1730	0.2843	0.0772	-0.9765	0.0140	0.0063	-0.0048	-0.0055	4.09	0.59
	(0.1046)	(0.0649)	(0.0733)	(0.0794)	(0.2466)	(0.0202)	(0.0228)	(0.0249)	(0.0151)		1.45
Pork	0.3163	0.0928	-0.5054	0.0964	-0.9006	-0.0136	0.0233	0.0755	-0.0222	2.05	0.85
	(0.0625)	(0.0239)	(0.0519)	(0.0455)	(0.1266)	(0.0102)	(0.0104)	(0.0132)	(0.0073)		2.14
Broilers	0.9915	0.0711	0.2721	-1.3346	-2.7810	0.1323	0.0100	-0.1172	0.0053	4.48	0.79
	(0.2111)	(0.0731)	(0.1284)	(0.2514)	(0.3603)	(0.0312)	(0.0258)	(0.0379)	(0.0177)		2.11
	Case (B) Price flexibilities for the second period, 1980-90										
Beefh	-0.2067	-0.0379	0.1804	0.0643	-0.8327	-0.0041	-0.0241	-0.0384	0.0145	1.13	0.91
	(0.0450)	(0.0178)	(0.0394)	(0.0329)	(0.0951)	(0.0057)	(0.0060)	(0.0097)	(0.0048)		1.85
Beefm	-0.1996	-0.2055	0.2046	0.2006	-0.7587	-0.0250	-0.0335	-0.0294	0.0203	3.92	0.53
	(0.0938)	(0.0738)	(0.1010)	(0.0955)	(0.3140)	(0.0187)	(0.0207)	(0.0269)	(0.0152)		1.15
Pork	0.3097	0.0668	-0.4981	0.1216	-1.1923	0.0121	0.0604	0.1126	-0.0429	1.83	0.80
	(0.0677)	(0.0330)	(0.0922)	(0.0740)	(0.1635)	(0.0096)	(0.0111)	(0.0213)	(0.0097)		1.57
Broilers	0.3115	0.1848	0.3434	-0.8396	-1.4907	-0.0036	-0.0324	-0.1253	0.0504	4.29	0.50
	(0.1597)	(0.0880)	(0.2088)	(0.2557)	(0.3907)	(0.0223)	(0.0294)	(0.0513)	(0.0244)		1.48
	Case (C) Price flexibilities for the whole period, 1970-90										
Beefh	-0.2333	-0.0312	0.1949	0.0696	-0.7984	-0.0078	-0.0250	-0.0381	0.0180	1.31	0.88
	(0.0364)	(0.0131)	(0.0249)	(0.0253)	(0.0707)	(0.0047)	(0.0048)	(0.0065)	(0.0035)		2.07
Beefm	-0.1643	-0.1586	0.242	0.081	-0.8411	-0.0067	-0.0228	-0.0250	0.0129	3.83	0.48
	(0.0690)	(0.0474)	(0.0588)	(0.0576)	(0.1897)	(0.0130)	(0.0146)	(0.0172)	(0.0101)		1.36
Pork	0.3346	0.079	-0.4776	0.064	-1.0924	-0.0001	0.0413	0.0917	-0.0314	1.96	0.83
	(0.0427)	(0.0192)	(0.0460)	(0.0377)	(0.0985)	(0.0067)	(0.0071)	(0.0109)	(0.0054)		1.89
Broilers	0.3374	0.0746	0.1805	-0.5925	-1.8628	0.0340	0.0071	-0.0763	0.0136	4.42	0.50
	(0.1227)	(0.0531)	(0.1063)	(0.1539)	(0.2708)	(0.0170)	(0.0177)	(0.0274)	(0.0132)		1.84

Note: The abbreviated notations are Beefh (high-quality beef), Beefm (manufacturing-grade beef), RMS (relative root-mean-square errors to sample means), DW (Durbin-Watson statistic), and D2, D3, and D4 seasonal dummy variables assigned for second, third, and fourth seasons. Figures in parentheses are the estimated standard errors.

An ordinary demand system (equation 33) incorporating the parametric constraints of homogeneity, symmetry, and Engel aggregation is also estimated for testing the structural change in meat demand. The testing procedure developed for the inverse demand system can be applied to this case as well. The estimation results are compiled in table 5. To test the demand structural changes between the two periods (1970-79 and 1980-90), the value of F-statistic is computed to be 0.74 with degrees of freedom k = 25 and nT-$2k$ = 282. The computed F-statistic is obviously less than the critical values $F(24, 200) = 1.57$ and $F(24, 400) = 1.54$ at 5-percent significance level. Again, there is no evidence of structural change in the meat demand. Meat prices and expenditures, not shifts in consumer tastes, are the overwhelming

Table 5--Testing structural change based on uncompensated ordinary demand system

Quantity	Beefh	Beefm	Pork	Broilers	Meat-exp	D2	D3	D4	Constant	RMS	R^2/DW
	Case (A) Price elasticities for the first period, 1970-79									Percent	
Beefh	-0.9980	-0.1300	-0.1634	-0.1481	1.4396	-0.0219	-0.0456	-0.0699	0.0366	1.91	0.86
	(0.0986)	(0.0618)	(0.0574)	(0.0188)	(0.1056)	(0.0086)	(0.0095)	(0.0074)	(0.0066)		2.79
Beefm	0.2951	-0.4834	0.5918	0.0944	-0.4979	0.0377	0.1455	0.1151	-0.0710	8.30	0.53
	(0.3609)	(0.2962)	(0.2083)	(0.0791)	(0.4457)	(0.0354)	(0.0384)	(0.0384)	(0.0270)		2.47
Pork	-0.0699	0.0471	-0.9691	-0.0308	1.0228	-0.0059	0.0283	0.1097	-0.0296	2.33	0.93
	(0.1110)	(0.0596)	(0.0759)	(0.0240)	(0.1380)	(0.0110)	(0.0123)	(0.0120)	(0.0084)		2.27
Broilers	-0.0841	0.0213	0.1596	-0.2820	0.1852	0.0831	-0.0233	-0.1029	0.0200	1.96	0.94
	(0.0973)	(0.0706)	(0.0691)	(0.0480)	(0.1151)	(0.0089)	(0.0099)	(0.0097)	(0.0068)		1.44
	Case (B) Price elasticities for the second period, 1980-90										
Beefh	-1.0520	-0.1592	-0.2349	-0.0862	1.5323	-0.0215	-0.0379	-0.0743	0.0321	1.58	0.91
	(0.1213)	(0.0577)	(0.0614)	(0.0325)	(0.1258)	(0.0082)	(0.0091)	(0.0070)	(0.0056)		2.40
Beefm	0.0309	-0.2799	0.4634	-0.0278	-0.1866	0.0307	0.0592	0.0273	-0.0305	7.11	0.26
	(0.3932)	(0.2528)	(0.2127)	(0.1046)	(0.5437)	(0.0362)	(0.0381)	(0.0309)	(0.0249)		2.66
Pork	-0.0177	0.0594	-0.7030	-0.1081	0.7693	0.0163	0.0534	0.1441	-0.0500	1.79	0.93
	(0.1228)	(0.0564)	(0.0762)	(0.0334)	(0.1440)	(0.0093)	(0.0110)	(0.0081)	(0.0065)		2.55
Broilers	0.2734	-0.0593	-0.1271	-0.2512	0.1643	0.0137	-0.0326	-0.0777	0.0367	2.41	0.77
	(0.1758)	(0.0835)	(0.0938)	(0.0743)	(0.1933)	(0.0126)	(0.0143)	(0.0110)	(0.0087)		2.04
	Case (C) Price elasticities for the whole period, 1970-90										
Beefh	-1.0364	-0.1497	-0.1949	-0.1352	1.5162	-0.0216	-0.0420	-0.0739	0.03475	1.67	0.90
	(0.0723)	(0.0401)	(0.0385)	(0.0193)	(0.0721)	(0.0055)	(0.0062)	(0.0056)	(0.0041)		2.56
Beefm	0.1146	-0.4006	0.4814	0.0737	-0.2691	0.0311	0.0942	0.0649	-0.0459	7.56	0.38
	(0.2576)	(0.1887)	(0.1459)	(0.0724)	(0.3226)	(0.0239)	(0.0265)	(0.0242)	(0.0178)		2.52
Pork	-0.0141	0.0465	-0.8379	-0.0765	0.8819	0.0057	0.0431	0.1304	-0.0412	2.09	0.92
	(0.0770)	(0.0412)	(0.0538)	(0.0232)	(0.0934)	(0.0069)	(0.0080)	(0.0070)	(0.0052)		2.24
Broilers	0.1106	0.042	0.0435	-0.1969	0.0008	0.0500	-0.0245	-0.0846	0.0247	2.70	0.78
	(0.1104)	(0.0636)	(0.0691)	(0.0548)	(0.1216)	(0.0090)	(0.0103)	(0.0092)	(0.0067)		1.94

Note: The abbreviated notations are Beefh (high-quality beef), Beefm (manufacturing-grade beef), RMS (relative root-mean-square errors to sample means), DW (Durbin-Watson statistic), and D2, D3, and D4 seasonal dummy variables assigned for second, third, and fourth seasons. Figures in parentheses are the estimated standard errors.

factors determining the magnitude of change in quarterly meat consumption. Again, meat prices and expenditures explain well the movement of meat consumption in the appendix figures 1 to 4 showing no evidence of structural change in meat demand. As discussed in Huang and Haidacher (*1989*) poultry has become relatively less expensive than beef and pork, and the decline in red meat consumption is consistent with substitution away from red meat to less expensive poultry. Thus, the changes in red consumption could be explained by changes in relative meat prices. A decrease in red meat prices through a reduction in production costs or improvements in marketing efficiency can be a very effective instrument in promoting red meat consumption.

Nutritional Implications

The issue of health and diet has become a major concern for consumers. Medical evidence increasingly links excessive saturated fat and cholesterol in the typical American's diet with heart disease, the leading cause of death in the United States. Also, some women and children in low-income households may have nutritional deficiencies and nutrition-related health problems (Senauer, Asp, and Kinsey, *1991*, p. 222). In 1990, the National Nutrition Monitoring and Related Research Act was passed. This act calls for a 10-year comprehensive plan to provide information about the role and status of nutrition factors that contribute to the health of Americans. An interagency board consisting of representatives from 22 Federal agencies coordinates the nutrition monitoring and related research activities.

A better understanding of the economic forces that influence consumer food choice and thus nutrient availability is important to food policy decision-makers. Food demand analysts need to broaden their theoretical and methodological base of research and provide timely information about the effects of economic factors on the nutritional status of consumers. Thus far, applied economists have not effectively explored the linkage of the determinants of food choice with consumer nutrient availability. Only a few articles have incorporated nutritional factors into food demand analyses. Some analysts typically used a cholesterol information index by measuring the number of medical journal articles that disseminate cholesterol information as a variable in demand equations (Brown and Schrader, *1990*; Capps and Schmitz, *1991*). Others used household survey data to fit demand equations for specific nutrients as functions of income and some sociodemographic variables (Devaney and Fraker, *1989*; Basiotis and others, *1983*). These nutrition-related studies using household survey data, however, do not provide information about the effects of price changes on consumer nutrient availability.

One objective of this study is to contribute to the methodology of linking food choice to nutritional status. Given the demand for foods derived from the classical demand framework with each food product containing a bundle of nutrient attributes, this study presents a statistical procedure developed in Huang (*1994c*) to measure the implied relationships of the nutrients in response to changes in food prices and income. This approach is different from that of Lancaster (*1966*). Under Lancaster's approach, consumers aim at attaining nutrient attributes they most desire; that is, maximizing a utility function defined by nutrient attributes but not by food quantities as perceived in the classical demand theory. Therefore, Lancaster's demand for foods is derived from the demand for the associated nutrient attributes but not the other way around as in this study.

To explore the linkage of the demand model to the nutrient availability to consumers, information about the nutrient values of each food consumed is needed. Let a_{ki} be the amount of the kth nutrient obtained from a unit of the ith food. The total amount of that nutrient obtained from various foods, say ϕ_k, may be expressed as

$$\phi_k = \Sigma_i \, a_{ki} \, q_i \qquad k = 1,2,\ldots,\ell; \; i = 1,2,\ldots,n \qquad (49)$$

The values of a_{ki}'s for nonfoods will be assigned to zero, and the terms associated with nonfoods disappear automatically. By incorporating the demand information shown in equation 6 for the quantity variable of equation 49, the relative changes of consumer nutrient availability can be expressed as functions of the relative changes in food prices and per capita income as follows:

$$d\phi_k/\phi_k = \Sigma_j\ (\Sigma_i\ e_{ij}\ a_{ki}\ q_i/\phi_k)\ dp_j/p_j + (\Sigma_i\ \eta_i\ a_{ki}\ q_i/\phi_k)\ dm/m$$

$$= \Sigma_j\ \pi_{kj}\ dp_j/p_j + \rho_k\ dm/m \qquad k = 1,2,\ldots,\ell;\ i,j = 1,2,\ldots,n \quad (50)$$

where $\pi_{kj} = \Sigma_i\ e_{ij}\ a_{ki}\ q_i/\phi_k$ is a price elasticity measure relating the effect of the jth food price on the availability of the kth nutrient, and $\rho_k = \Sigma_i\ \eta_i\ a_{ki}\ q_i/\phi_k$ is an income elasticity measure relating the effect of income on the availability of that nutrient.

Obviously, the measurement of π_{kj} represents the weighted average of some direct- and cross-price elasticities (e_{ij}'s) in response to the jth price with weights expressed by the share of the kth nutrient contributed by each food item (that is, $a_{ki}\ q_i/\phi_k$). Similarly, the measurement of ρ_k represents the weighted average of all expenditure elasticities (η_i's) with weights defined the same as those in measuring π_{kj}. From these nutrient elasticity measurements, a change in a particular food price or income will affect all food quantities demanded through the interdependent demand relationships and thus cause the levels of consumer nutrient availability to change simultaneously. The unique feature of this approach for measuring nutrient elasticities is that some perceived direct-price, cross-price, and income effects are incorporated into the measurement.

To illustrate the methodology, the developed procedure is applied to measure implied nutrient elasticities based on the estimated quarterly demand elasticities for meats. The demand system for meats is implicitly assumed to be weakly separable from the demand for other goods. The separability assumption may be too strong for nutritional analysis, because the interactions and substitutions of food components among meats and nonmeat products within the food diet are not fully considered. Thus the information obtained in this section should be interpreted as the measurement of changes in nutrient availability from meat as the demand for meat items changes. An option of complete nutritional analysis might be to include composite variables for aggregate nonmeat food groups such as dairy products, cereals, fruits, and vegetables in the model. In addition to lack of quarterly nonmeat aggregate data, it is difficult to define a set of meaningful nutrients to represent a great diversity of food products in a food group.

To measure the nutrient elasticities for meats, information about the nutrition attributes of meat consumption (published by the U.S. Department of Agriculture, Human Nutrition Information Service, Agricultural Handbook numbers 8-5, 8-10 and 8-13) is used. The nutritive values of choice beef (with carcass, separable lean and fat) are used to represent the high-quality beef, regular-ground beef for manufacturing-grade beef, pork (with fresh, carcass, separable lean and fat) for pork, and chicken (broilers or fryers with flesh, skin, giblets, and neck) for broiler. These nutritive values of

12 selected nutrients are compiled in table 6. Food energy is measured in kilocalories (kcal), protein and fat in grams, and all other nutrients in milligrams. Each nutritive value is measured by the edible portion of meat per pound as purchased, which deviates from disappearance data used in this study. If we assume a plausible fixed proportion between the amount of edible portion of a particular meat and its disappearance meat data, however, the relative changes in quantities (dq_i/q_i 's) and thus the measured nutrient demand elasticities generated from either set of data should be the same.

The food energy contents (table 6) of both manufacturing-grade beef and pork are relatively higher (about 1,400 kcal) than high-quality beef (1,063 kcal) and broiler meat (665 kcal). The protein contents of both pork and broiler meat are relatively lower (respectively, 52 and 57 grams) than high-quality beef and manufacturing-grade beef (respectively, 63 and 75 grams). Fat and cholesterol are two common health concerns. The fat content in pork and manufacturing-grade beef is relatively high, about 130 and 120 grams per pound, while for high-quality beef it is about 88 grams per pound, and for broiler meat about 46 grams per pound. For the nutritive value of cholesterol, except for manufacturing-grade beef having a high level of 384 milligrams, all other meats are about 272 to 281 milligrams.

The elasticities of the 12 nutrients in response to meat prices and per capita meat expenditure can be computed on the basis of equation 50. They are $\pi_{kj} = \Sigma_i \; e_{ij} \; a_{ki} \; q_i/\phi_k$ for measuring nutrient price elasticity, and

Table 6--Nutritive value of the edible part of meat per pound

Nutrient	Unit	Beefh	Beefm	Pork	Broiler
Food energy	kcal	1,063.00	1,408.00	1,398.00	665.00
Protein	g	63.32	75.40	51.76	57.38
Fat	g	87.91	120.44	130.45	46.42
Cholesterol	mg	272.00	384.00	274.00	281.00
Calcium	mg	28.00	38.00	71.00	35.00
Phosphorus	mg	564.00	587.00	576.00	467.00
Iron	mg	6.69	7.86	2.57	4.09
Potassium	mg	977.00	1035.00	941.00	593.00
Sodium	mg	215.00	308.00	157.00	219.00
Thiamin	mg	0.28	0.17	2.21	0.19
Riboflavin	mg	0.60	0.69	0.77	0.58
Niacin	mg	12.94	20.32	14.31	20.78

Note: The abbreviated notations are Beefh (high-quality beef) and Beefm (manufacturing-grade beef). The abbreviated nutritive values are kcal (kilocalories), g (grams), and mg (milligrams). Source: USDA, Human Nutrition Information Service, Agricultural Handbook Nos. 8-5, 8-10, 8-13.

$\rho_k = \Sigma_i \ \eta_i \ a_{ki} \ q_i/\phi_k$ for measuring nutrient meat-expenditure elasticity. For example, to calculate the elasticities of protein in response to the price of high-quality beef (Beefh) and meat expenditure, one needs to know that the quarterly meat consumption at the sample means are 21.03 pounds (Beefh), 6.97 pounds (Beefm, manufacturing-grade beef), 16.57 pounds (Pork), and 12.18 pounds (Broiler). This combination of meat consumption yields 3,413 grams of protein with nutrient shares being 39.01 percent (Beefh), 15.39 percent (Beefm), 25.13 percent (pork), and 20.47 percent (broiler). Using the nutrient share information in conjunction with meat price elasticities from table 2, one can directly compute the protein elasticities in response to high-quality beef price and meat expenditure being -0.3676 and 0.7719. Finally, since the nutrient elasticities are linear functions of demand elasticities e_{ij}'s or η_i's, the standard errors of estimated nutrient elasticities are computable using the information of the covariance matrix of the estimated demand elasticities in the meat demand system.

The computed nutrient elasticities in table 7 show the effects of changes in quarterly meat prices and meat expenditures on the nutrients available from meat consumption. For example, a marginal 1-percent increase in the price of high-quality beef (holding other meat prices and meat expenditure the same) will affect the amount of all meat consumption through an interdependent meat demand structure expressed by direct- and cross-price elasticities. As shown in table 7, these changes in meat consumption will reduce quarterly per capita food energy from meat by 0.3386 percent, protein by 0.3676 percent, and fat by 0.3302 percent. A marginal 1-percent increase in the price of manufacturing-grade beef, however, may cause this nutrient available from meat to decrease by only about 0.09 percent. In general, the estimated nutrient elasticities in response to the price change of high-quality beef are the most elastic, but the elasticities in response to the price changes of broiler and manufacturing-grade beef are the least elastic.

The nutrient meat-expenditure elasticity estimates range from 0.65 to 0.89 (table 7). These meat-expenditure (not income) elasticities, however, cannot directly make policy implications about income changes. One way to derive the nutrient income elasticities is by multiplying the meat-expenditure elasticities by the expenditure-income elasticity, which is estimated to be 0.5225 from an auxiliary regression with per capita meat expenditures as a function of per capita personal consumption expenditure. Accordingly, the nutrient income elasticities are estimated ranging from 0.34 to 0.46. These nutrient income elasticities, if available for a complete set of food commodities, are useful information for food policy decisionmakers to evaluate the effects of income changes on consumer dietary quality, especially for monitoring the segment of the population whose incomes fall below the poverty level. The magnitude and nature of the problems of hunger and poverty in the United States have been well described in Senauer, Asp, and Kinsey (*1991*, chapter 9). Some Government food assistance programs are aimed at increasing food purchasing power of low-income households. In particular, the Food Stamp Program issues monthly allotments of coupons to eligible households that can be used to purchase food at grocery stores. Assuming that welfare recipients have the same income elasticity as the average person, food policy decision-makers can use the nutrient income elasticities to assess the Food Stamp Program effects on the nutrient availability from meat to welfare recipients.

Table 7--Quarterly nutrient elasticities based on meat demand

Nutrient	Price				Meat-exp	Income
	Beefh	Beefm	Pork	Broiler		
Food energy	-0.3386 (0.0270)	-0.0924 (0.0167)	-0.2947 (0.0141)	-0.0893 (0.0072)	0.8150 (0.0280)	0.4258
Protein	-0.3676 (0.0255)	-0.0998 (0.0164)	-0.2036 (0.0137)	-0.1009 (0.0087)	0.7719 (0.0280)	0.4033
Fat	-0.3302 (0.0285)	-0.0902 (0.0174)	-0.3219 (0.0154)	-0.0858 (0.0076)	0.8281 (0.0293)	0.4327
Cholesterol	-0.3245 (0.0307)	-0.0962 (0.0194)	-0.2129 (0.0160)	-0.0976 (0.0098)	0.7312 (0.0329)	0.3820
Calcium	-0.2237 (0.0348)	-0.0495 (0.0175)	-0.3886 (0.0195)	-0.0953 (0.0094)	0.7571 (0.0356)	0.3956
Phosphorus	-0.3634 (0.0209)	-0.0876 (0.0123)	-0.2596 (0.0107)	-0.1011 (0.0067)	0.8116 (0.0214)	0.4240
Iron	-0.4677 (0.0285)	-0.1352 (0.0206)	-0.1201 (0.0177)	-0.0974 (0.0092)	0.8206 (0.0374)	0.4287
Potassium	-0.3933 (0.0194)	-0.0976 (0.0124)	-0.2627 (0.0100)	-0.0961 (0.0055)	0.8497 (0.0207)	0.4440
Sodium	-0.3504 (0.0329)	-0.1092 (0.0218)	-0.1602 (0.0180)	-0.0986 (0.0110)	0.7184 (0.0374)	0.3754
Thiamin	-0.1351 (0.0558)	0.0096 (0.0295)	-0.6769 (0.0386)	-0.0862 (0.0163)	0.8886 (0.0676)	0.4643
Riboflavin	-0.3203 (0.0249)	-0.0781 (0.0139)	-0.2832 (0.0127)	-0.1001 (0.0077)	0.7817 (0.0250)	0.4084
Niacin	-0.2669 (0.0371)	-0.0839 (0.0222)	-0.1909 (0.0195)	-0.1043 (0.0133)	0.6460 (0.0387)	0.3375

Note: The abbreviated notations are Beefh (high-quality beef), Beefm (manufacturing-grade beef), and Meat-exp (meat expenditure). Income elasticities are computed by multiplying the meat-expenditure elasticities by 0.5225 (estimated meat expenditure-income elasticity). Figures in parentheses are the estimated standard errors.

While focusing on the methodology, this study can be further extended to develop comprehensive food demand and nutrition research. Some collaborative research between economists and nutritionists to obtain more nutrient information is required. The following three problems need to be considered. First, most available nutrition information gives detailed nutritive values of the edible portion of food products, which deviates from disappearance data commonly used by food demand analysts. Second, the use of disappearance data can hardly distinguish nutritive values from different food preparation methods such as chicken fried in animal fat or vegetable oils, which has far different properties from those of roasted chicken. Third, nutrient information for all foods is needed to provide a total nutrient profile. This is especially true when considering formulated foods such as pizza, which combine meat, cheese, vegetables, and wheat flour into one food dish.

Consumer Welfare Effects

What are the effects of meat quantity changes on meat prices and consumer welfare? The question is frequently raised in the study of meat marketing and trade. Marshall's concept of consumer surplus, which is defined as the area under the uncompensated demand curve resulting from a change in prices, has been widely used as a welfare measure to analyze agricultural policy. A study of agricultural price policy by Tolley, Thomas, and Wong (*1982*) is one example. The use of consumer surplus has certain operational advantages. It can be demonstrated that the competitive equilibrium in the market for a single good maximizes the sum of consumer and producer surplus. The problem of using consumer surplus, as discussed in Hausman (*1981*), is its rigid assumption on the constancy of marginal utility of income so that the primary condition to correspond to the compensating variation can be satisfied.

The problem with consumer surplus can be avoided by moving from the uncompensated to the compensated demand function. As Deaton and Muellbauer (*1980*, pp. 185-186) noted, Hicksian demand functions are the derivatives of the expenditure function, which calculates the minimum amount of expenditure necessary to get to a given level of utility. The price increases (or decreases) have similar effects on consumer welfare as do decreases (or increases) in expenditures. For any set of price changes, there is a compensating expenditure change that will offset the effect of the price change. Thus, the properties of compensated demand functions allow one to calculate welfare effects in terms of compensating variation (CV) in expenditure as a welfare measure.

Willig (*1976*), Hausman (*1981*), Just, Hueth and Schmitz (*1982*), and Schonkwiller (*1991*) have all proposed approximated Hicksian welfare measures for the case when only one commodity price changes. Given the interdependent nature of demands in consumers' budgeting, such a welfare analysis is obviously not practical for empirical application. To accommodate for multiple price effects, this study approximates the compensating variation measure as a function of all price changes and compensated price elasticities obtained from estimated inverse and ordinary demand systems. The methodology for measuring these effects is similar to that used by Huang (*1993b*), and Huang and Hahn (*1994*).

For calculation of consumer welfare, let us define the expenditure function as $E(p,u)$ for a vector of prices p and a utility level u. Suppose at some initial price level p^0 and expenditure level $E(p^0,u^0)$, the consumer achieves utility u^0. The compensating variation required by moving to price level p^1 is given by

$$CV = E(p^1,u^0) - E(p^0,u^0) \tag{51}$$

In the above U.S. meat example, if p^0 and p^1 are regarded, respectively, as the price before and after meat quantity changes, then the measurement of CV reflects the change in expenditures necessary to compensate consumers for the effects. A positive CV implies a rise in the cost of living, and the consumer welfare is decreasing. On the other hand, a negative CV implies a drop in the cost of living and a gain in consumer welfare.

To measure CV, let $q_i^h(p^1,u^0)$ be the Hicksian (compensated) demand for the ith good at given price vector p^1 while maintaining the same initial utility level u^0, and let $q^h(p^1,u^0)$ be the associated vector of Hicksian quantities demanded. The expenditure $E(p^1,u^0)$ can be expressed as the inner product of p^1 and $q^h(p^1,u^0)$. The initial expenditure $E(p^0,u^0)$ can be similarly expressed as the inner product of p^0 and q^0. Thus the CV in equation 51 can be written as

$$CV = p^1.q^h(p^1,u^0) - p^0.q^0 \tag{52}$$

By further defining $dp = p^1 - p^0$ as a vector of price changes, and $dq^h = q^h(p^1,u^0) - q^0$ as a vector of compensated quantity changes, the above CV equation is transformed into:

$$CV = p^1.dq^h + q^0.dp \tag{53}$$

Given the initial quantities demanded q^0, and the projected price vectors p^1 and dp from the inverse demand system, the key question for computing the compensating variation CV is to find a vector of changes in compensated quantities demanded dq^h.

The change of Hicksian demand for the ith good (dq_i^h) in equation 53 can be approximated by applying the first-order differential form as

$$dq_i^h = \boldsymbol{\Sigma}_j \ (\partial q_i^h/\partial p_j) \ dp_j \qquad i,j = 1,2,..,n \tag{54}$$

$$dq_i^h/q_i = \boldsymbol{\Sigma}_j \ e_{ij}* \ (dp_j/p_j) \qquad i,j = 1,2,..,n \tag{55}$$

where $e_{ij}* = (\partial q_i^h/\partial p_j)(p_j/q_i)$ is a compensated price elasticity of the ith commodity with respect to a price change of the jth commodity. These compensated price elasticities can be derived from a linkage condition (shown in equation 11) by using the information of the uncompensated price elasticity estimates (e_{ij}'s) in an ordinary demand system:

$$e_{ij}* = e_{ij} + w_j \ \eta_i \qquad i,j = 1,\ 2,\ .\ .\ .\ .\ ,\ n \tag{56}$$

In short, to measure the Hicksian compensating variation (CV) of equation 53, the essential unknown component of the change in compensated quantities demanded dq^h can be calculated on the basis of information about the uncompensated price elasticities and the price changes projected from an inverse demand system. The unique feature of this approach is that all potential direct- and cross-commodity effects are incorporated into the price forecasting and the welfare measurement.

Some empirical results of simulated price changes and consumer welfare for U.S. quarterly demand for meats are discussed below. To provide information for calculating the compensating variation (CV), the estimates of uncompensated price elasticities from table 2 are compiled in case (A) of table 8. These elasticities and associated covariance of errors are used to compute the compensated price elasticities and their standard errors contained in case (B) of the same table. As expected, all statistically significant estimates of compensated cross-price elasticities are positive, implying that meats are substitutable with each other.

Table 8--Demand elasticities used in consumer welfare measurement

	Beefh	Beefm	Pork	Broiler	Meat-exp	Constant	D2	D3	D4	RMS	R^2/DW
Quantity: Case (A) Uncompensated elasticities										Percent	
Beefh	-1.0364	-0.1497	-0.1949	-0.1352	1.5162	0.0348	-0.0216	-0.0420	-0.0739	1.67	0.90
	(0.0723)	(0.0401)	(0.0385)	(0.0193)	(0.0721)	(0.0041)	(0.0055)	(0.0062)	(0.0056)		2.56
Beefm	0.1146	-0.4006	0.4814	0.0737	-0.2691	-0.0459	0.0311	0.0942	0.0649	7.56	0.38
	(0.2576)	(0.1887)	(0.1459)	(0.0724)	(0.3226)	(0.0178)	(0.0239)	(0.0265)	(0.0242)		2.52
Pork	-0.0141	0.0465	-0.8379	-0.0765	0.8819	-0.0412	0.0057	0.0431	0.1304	2.09	0.92
	(0.0770)	(0.0412)	(0.0538)	(0.0232)	(0.0934)	(0.0052)	(0.0069)	(0.0080)	(0.0070)		2.24
Broiler	0.1106	0.0420	0.0435	-0.1969	0.0008	0.0247	0.0500	-0.0245	-0.0846	2.70	0.78
	(0.1104)	(0.0636)	(0.0691)	(0.0548)	(0.1216)	(0.0067)	(0.0090)	(0.0103)	(0.0092)		1.94
Quantity: Case (B) Compensated elasticities											
Beefh	-0.2702	-0.0041	0.2514	0.0229							
	(0.0616)	(0.0390)	(0.0340)	(0.0184)							
Beefm	-0.0214	-0.4264	0.4022	0.0456							
	(0.2050)	(0.1823)	(0.1202)	(0.0666)							
Pork	0.4316	0.1312	-0.5783	0.0155							
	(0.0584)	(0.0392)	(0.0496)	(0.0217)							
Broiler	0.1110	0.0421	0.0437	-0.1968							
	(0.0889)	(0.0613)	(0.0612)	(0.0549)							
Weight	0.5054	0.0961	0.2943	0.1042							

Note: Compensated elasticities in case (B) are computed from uncompensated case (A). The abbreviated notations are Beefh (high-quality beef), Beefm (manufacturing-grade beef), Meat-exp (Meat expenditure), Weight (expenditure weight), RMS (relative root-mean-square errors to sample means), DW (Durbin-Watson statistic), and D2, D3, and D4 seasonal dummy variables assigned for second, third, and fourth seasons. Figures in parentheses are the estimated standard errors.

While with a focus on methodology issue, this report illustrates the potential effects of a 1-percent change in meat quantities on meat prices and consumer welfare. According to the historical pattern of U.S. meat marketing and trade, some useful scenarios for simulation would be the decrease for high-quality beef and broilers and the increase for manufacturing-grade beef and pork in domestic market. The actual level of price and quantity in the fourth quarter of 1990 is served as the baseline for simulation. The simulation results are summarized in table 9. Per capita quarterly savings (the negative value of the CV measures) in meat expenditures as shown in the last column of the table are used to represent consumer welfare. The results contained in this table are slightly different from those reported in Huang (*1993b*), because additional seasonal dummy variables are included in the demand model of this study.

In table 9, a marginal 1-percent decrease of high-quality beef in scenario 1 would cause all meat prices to increase and the economic well-being of consumers to decrease by $0.58 more per person per quarter. On the other hand, a marginal 1-percent increase in the amount of manufacturing-grade beef in scenario 2 would substantially decrease the prices of both kinds of beef and the broilers, and the consumer welfare would increase by $0.11 per person per quarter. The simulation results in scenario 3

Table 9--Simulated effects of meat prices and consumer welfare

Scenario	Percentage change in amount of meats: -1% Beefh	+1% Beefm	+1% Pork	-1% Broiler	Percentage change in prices: Beefh	Beefm	Pork	Broiler	Per capita quarterly savings (-CV)
					----------- Percent			-----------	Dollars
(1)	-				0.637	0.589	0.218	0.604	-0.5769
(2)		+			-0.108	-0.239	-0.026	-0.104	0.1102
(3)			+		-0.040	-0.006	-0.799	-0.368	0.3458
(4)				-	0.014	0.007	0.050	0.787	-0.1411
(5)	-	+			0.529	0.350	0.192	0.500	-0.4668
(6)	-		+		0.597	0.584	-0.582	0.236	-0.2299
(7)	-			-	0.651	0.596	0.267	1.391	-0.7180
(8)		+	+		-0.148	-0.245	-0.825	-0.472	0.4557
(9)		+		-	-0.094	-0.233	0.024	0.682	-0.0309
(10)			+	-	-0.026	0.001	-0.749	0.419	0.2045
(11)	-	+	+		0.489	0.345	-0.608	0.132	-0.1202
(12)	-	+		-	0.543	0.357	0.241	1.287	-0.6079
(13)	-		+	-	0.610	0.591	-0.532	1.023	-0.3712
(14)		+	+	-	-0.134	-0.238	-0.775	0.315	0.3144
(15)	-	+	+	-	0.503	0.351	-0.558	0.919	-0.2615

Note: The abbreviated notations are Beefh (high-quality beef) and Beefm (manufacturing-grade beef). The signs + and - in each simulation represent increases by 1 percent for pork and manufacturing-grade beef, and decreases by 1 percent for high-quality beef and broilers. Per capita quarterly savings are measured as the negative value of the compensating variation (CV).

reflect a marginal 1-percent increase in pork quantity. The prices of pork, broilers, and high quality beef would decrease substantially, and consumers would save $0.35 per person. In scenario 4, a marginal 1-percent decrease in the amount of broilers would increase all meat prices, especially for broilers and pork, and this change would cost consumers $0.14 per person. Scenarios 5 to 15 are designated to reflect the mixed effects on meat prices and consumer welfare under various combinations of changes in the amount of meats.

The simulation results contained in table 9 are as expected. An expansion of manufacturing-grade beef and pork in the domestic market would lower all meat prices and increase the economic well-being of consumers, while the opposite effects would occur with a decrease in high-quality beef and broiler supplied. The changes in consumer welfare in terms of the amount of savings are much more sensitive in the categories of high-quality beef and pork. This is in general consistent with their meat expenditure shares, in which the average shares in the sample period are about 50 percent spent on high-quality beef, 29 percent on pork, and 10 percent on broilers and manufacturing-grade beef.

These simulated changes in meat expenditures could have significant effects on aggregate consumer welfare. For example, a 1-percent increase in the availability of pork would save consumers about $0.35 or 0.31 percent of their approximate $114 quarterly meat budget in the baseline (the fourth quarter of 1990). Given the number of U.S. consumers--about 250 million persons--the quarterly savings would be $87.5 million for the Nation. Finally, since the model specified in this study is focused on consumers' behavior but does not explicitly recognize the supply side of the meat markets, an extension of this research to a general demand-supply equilibrium model would make the empirical results more practical and useful.

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Appendix:

Graphic Comparison of Actual and Simulated Results

To provide information about the potential analytical and forecasting capability of demand systems, an *ex post* simulation was conducted over the sample period by using the following empirical demand systems:

Uncompensated ordinary demand system (equation 33):

$$q_1' = \Sigma_j\, e_{1j}\, p_j' + \eta_1\, m' + \delta_1 + \delta_{12}\, d_2 + \delta_{13}\, d_3 + \delta_{14}\, d_4$$

$$\vdots$$

$$q_n' = \Sigma_j\, e_{nj}\, p_j' + \eta_n\, m' + \delta_n + \delta_{n2}\, d_2 + \delta_{n3}\, d_3 + \delta_{n4}\, d_4$$

Uncompensated inverse demand system (equation 35):

$$r_1' = \Sigma_j\, f_{1j}\, q_j' + \delta_1 + \delta_{12}\, d_2 + \delta_{13}\, d_3 + \delta_{14}\, d_4$$

$$\vdots$$

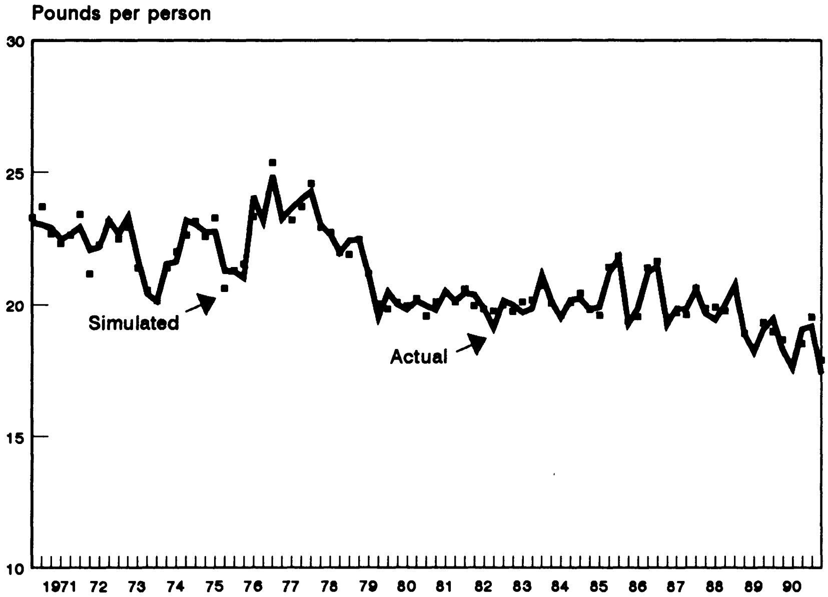
$$r_n' = \Sigma_j\, f_{nj}\, q_j' + \delta_n + \delta_{n2}\, d_2 + \delta_{n3}\, d_3 + \delta_{n4}\, d_4$$

where variables q_i', p_i', m_t', and r_i' are the relative changes in quantity, price, per capita expenditure, and normalized price, and d_i's are the dummy variables. The parametric estimates of the demand systems contained in cases (*A*) and (*B*) of table 2 are used for simulation.

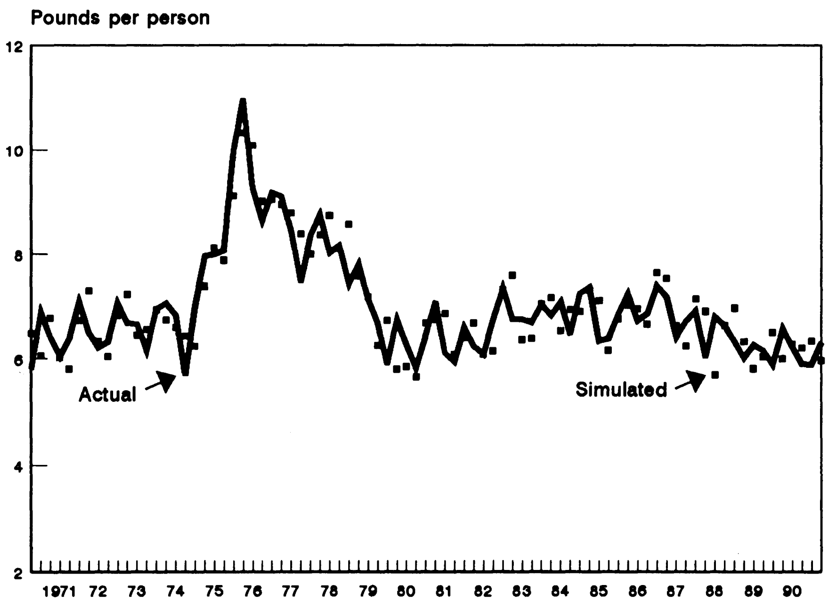
By performing simulations, the actual observations of variables appearing on the right-hand side of each equation are used as input information to generate the simulation results for a given quarter. The procedure is then repeated to cover the whole sample period. The immediate simulation results from the models are expressed in terms of relative changes in quantities demanded (ordinary demand model) or normalized prices (inverse demand model). In practice, it is desirable to present the simulation results expressed in terms of quantity or price levels by transforming the projected relative changes into levels on the basis of actual observed levels available in the previous quarter.

The actual and simulated levels of quantities demanded and normalized prices are depicted in appendix figures 1 to 4 and 5 to 8, respectively. These graphic presentations provide a better comprehension of simulation performance and help to ascertain the consistency of the relative root-square errors to sample means (*RMS*) as shown in table 2.

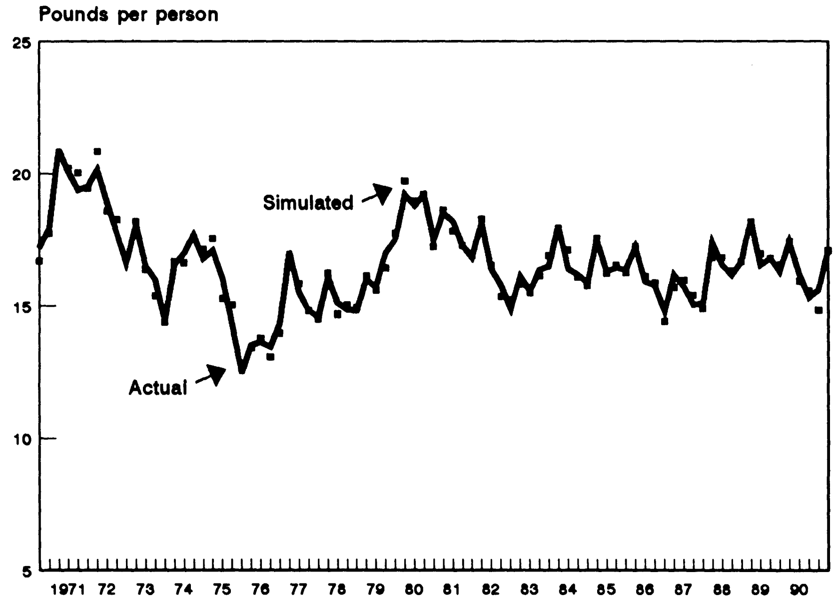
Appendix figure 1
High-quality beef: Quantity



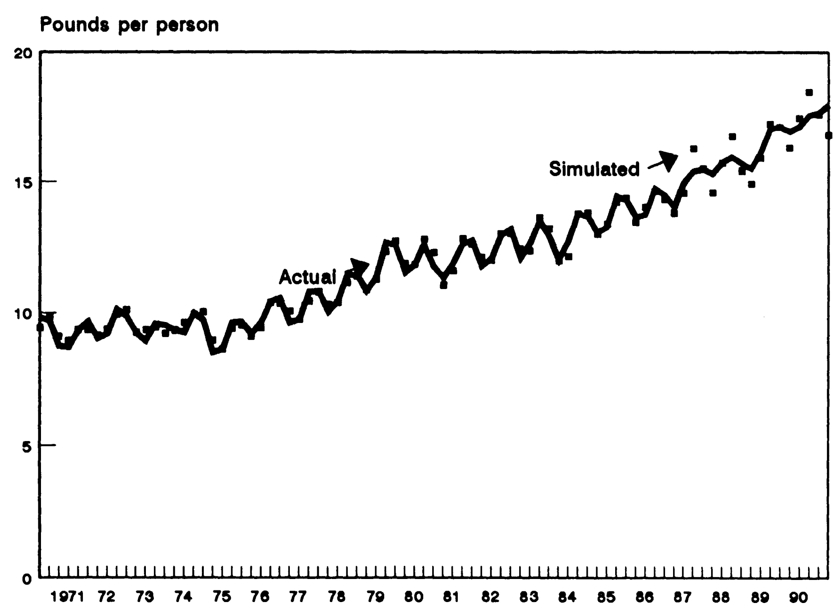
Appendix figure 2
Manufacturing-grade beef: Quantity



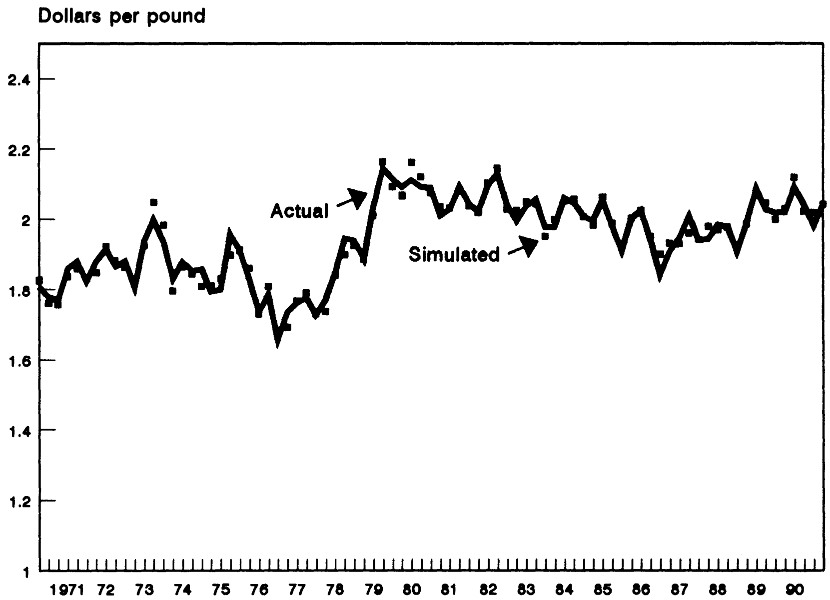
Appendix figure 3
Pork: Quantity



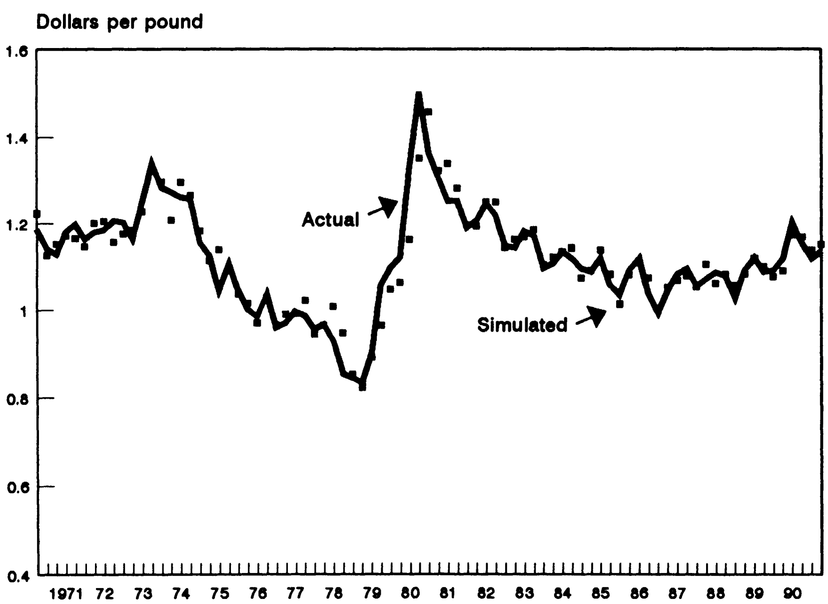
Appendix figure 4
Broilers: Quantity



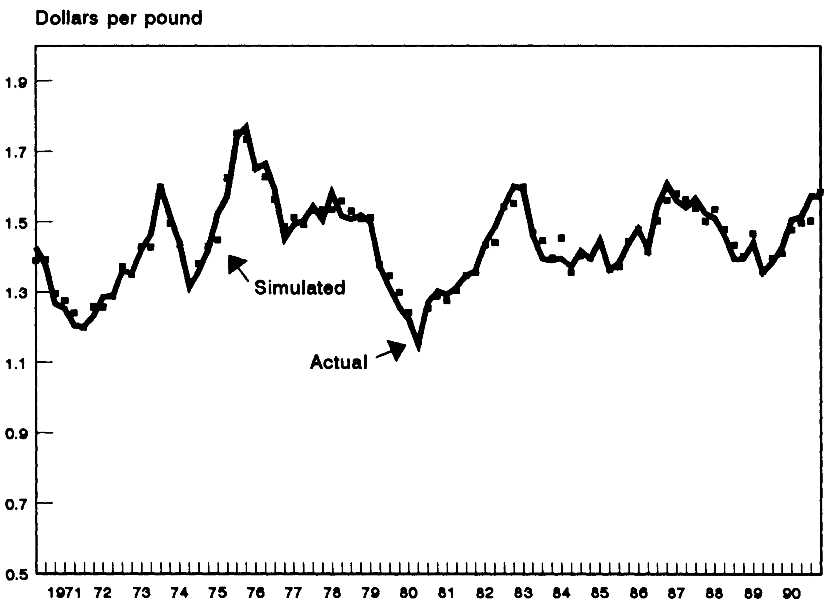
Appendix figure 5
High-quality beef: Normalized price



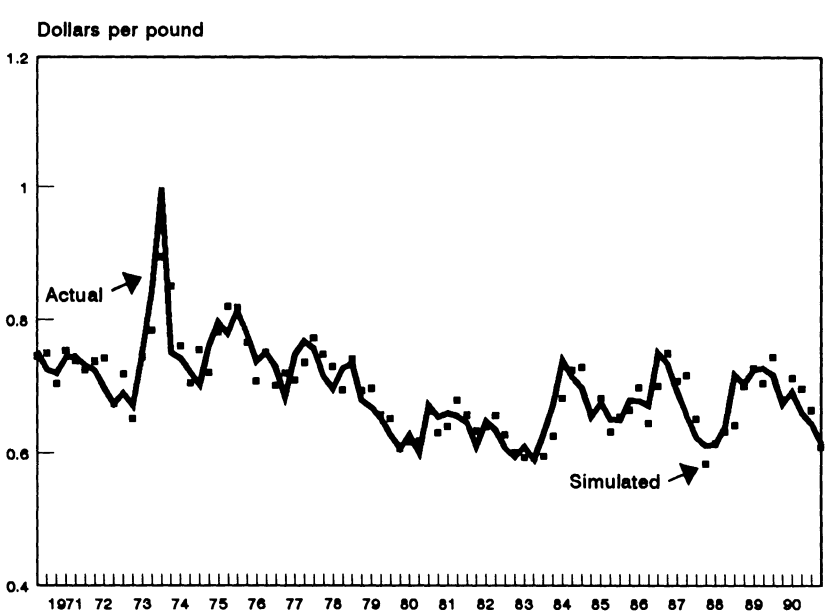
Appendix figure 6
Manufacturing-grade beef: Normalized price



Appendix figure 7
Pork: Normalized price



Appendix figure 8
Broilers: Normalized price



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